2.0 ENVIRONMENTAL SETTING

Florida's east coast is approximately 800 km long and represents part of the passive, slowly subsiding eastern North American continental margin (Klitgord et al., 1988). It lies within the Coastal Plain Physiographic Province that stretches along the Atlantic and Gulf Coasts of North America from Long Island to Mexico and is underlain by thick sedimentary sequences of Tertiary and Quaternary age, with the oldest of the exposed rocks in this region belonging to the Eocene-Ocala Group (Meisburger and Duane, 1971). Coastal features are represented by a series of low barrier beaches and islands, and include the Cape Canaveral peninsula, one of the largest cuspate forelands in the world (Figure 2-1). The barrier islands are punctuated by numerous inlets, providing exchange of sediment and water between estuaries and the continental shelf, primarily as a function of tide. The project site is located along the central portion of the east coast of Florida, extending from about 80°36'50"W, 28°37"49'N (False Cape) to about 80°04'15"W, 26°56'40"N (Jupiter Inlet). This area encompasses approximately 200 km of exposed coastline that includes five major inlets (Port Canaveral, Sebastian, Fort Pierce, St. Lucie, and Jupiter). The offshore portion of the study area extends east from the high-water shoreline across the southernmost section of the East Coast Shelf (known as the Florida Continental Shelf) and is bounded to the east by the steep Florida-Hatteras Slope (Figure 2-1). Although the offshore Federal-State jurisdictional boundary marks the direct landward limit of the study area, the ultimate use of sand extracted from the OCS is for beach replenishment along the central east Florida outer coast. Consequently, a description of the environmental setting from the outer coast to the OCS is pertinent for addressing the overall study purpose.

Florida beaches historically have attracted numerous visitors and are responsible for a majority of tourism in the State (Pilkey et al., 1984). According to the Florida Department of Environmental Protection, beaches have attracted 14 million permanent residents to the State, 75% of which live within 10 miles of the coast (State of the Coast Report, 1996). Recent increases in tourism have led to extensive shorefront development and growth of coastal communities. The degree of development along different portions of the coastline varies greatly, but the maintenance of beaches is of vital social and economic importance to the communities. A combination of natural shoreline retreat and storm damage has provided incentive for beachfront property owners and communities to install seawalls, sloping revetments, and groins, in addition to supporting beach nourishment (Pilkey et al., 1984).

Most of the barrier islands in the study area have been nourished periodically along portions of their outer coasts since the 1970s. The need for sand to replenish eroding beaches continues to be an area of concern for local, State, and Federal resource agencies, prompting the exploration and environmental evaluation of offshore resource sites for future use. Beach nourishment has been combined with structural development to further prevent erosion problems and stabilize Federal entrances. Engineered inlets were created at four of the five entrances within the study area, and each was armored with rock jetties on both banks by 1954. Structure placement and inlet development have contributed to the interruption of natural littoral processes within the study area, resulting in erosional "hot spots" on the downdrift sides of entrances. Estimated volumes and locations of beach nourishment activities as well as the history of structure development are summarized in Section 3.1 of this report.

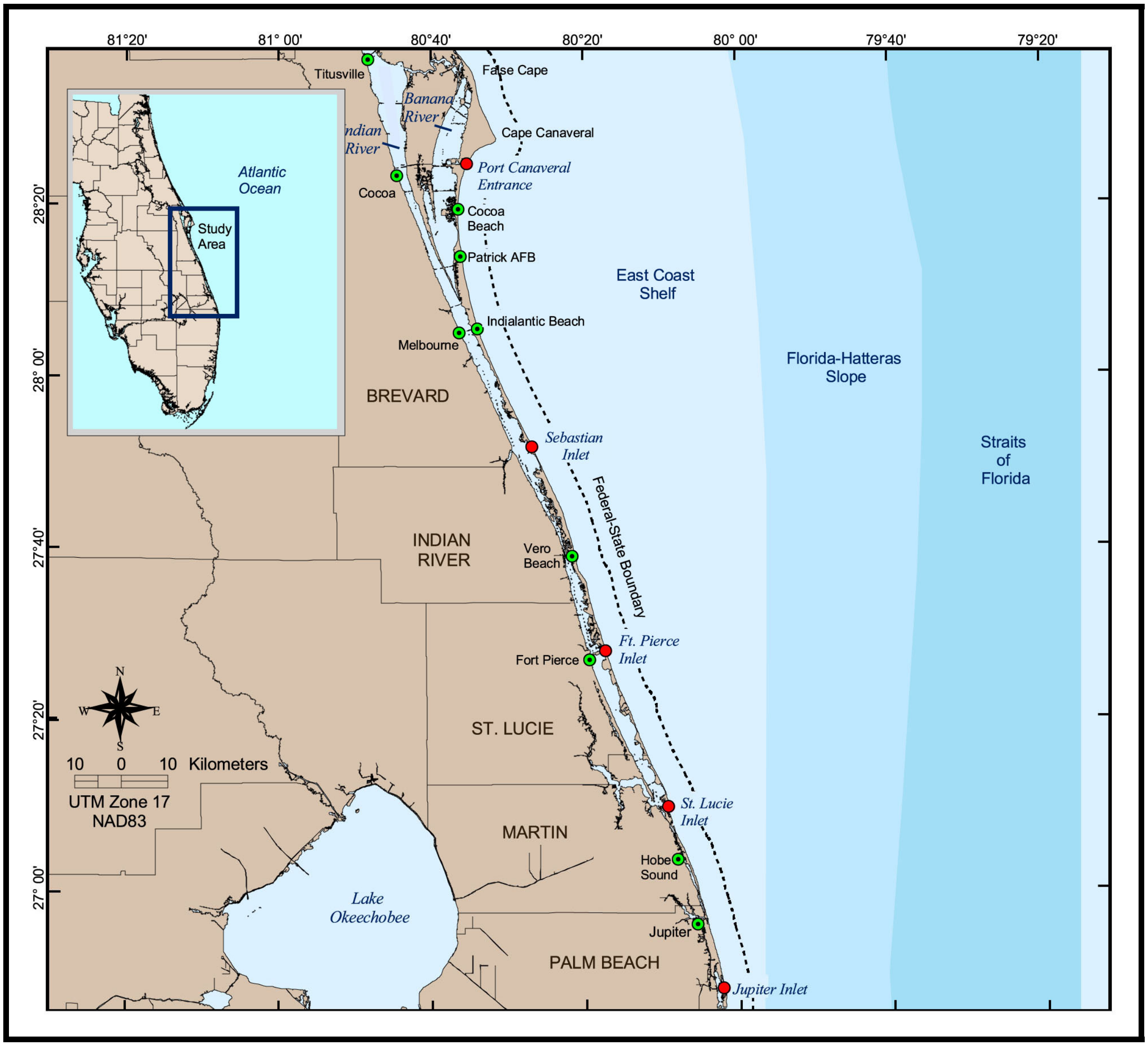

Figure 2-1. Central east Florida study area, including inlet locations and the Federal-State boundary.

Within the northern portion of the study area, sandy beaches exist along the base of the Canaveral Peninsula beach ridge complex. Field and Duane (1974) characterized beach sediments in this region using 24 samples collected along the outer coast between False Cape and Melbourne Beach (Figure 2-2). Their study found that areal beach sediment was composed primarily of coarse to fine grained sands, with a high percentage of shell fragments mixed throughout. Sediment size tends to vary considerably along the outer coast, with finest sediments located just south of Cape Canaveral. Lateral transport by littoral currents and onshore transport during optimal wave conditions are the major processes influencing the composition of beach sands in this area (Field and Duane, 1974). Grain-size variations observed within the region are the result of changes in shoreline

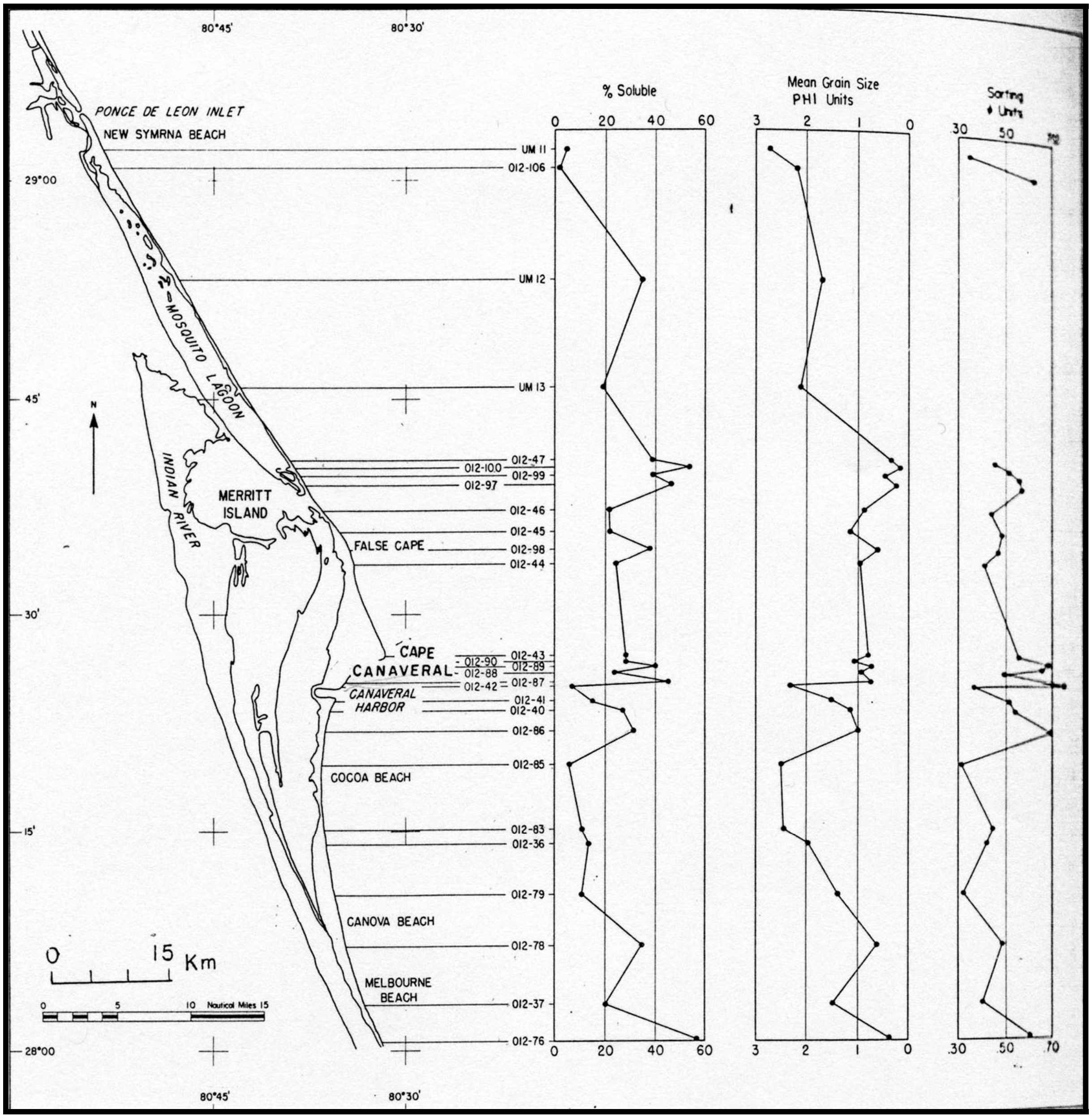

Figure 2-2. Percent soluble, mean grain size, and sorting for beach samples showing the direct influence of shell material on textural parameters (from Field and Duane, 1974).

orientation and exposure, in addition to the availability of offshore materials, with increases in sediment grain size being directly related to increases in the percentage of shell fragments (Field and Duane, 1974). Stauble and McNeill (1985) documented similar trends and noted that the shoreline on the south side of the Cape exhibits noticeable changes in sand grain size, shell content, and beach slope than that observed on beaches to the north. Beaches close to the south side of the Cape are characterized by broad, flat slopes with fine-grained composition. Further south, beaches narrow, steepen, and become coarser-grained with an increase in shell fragments due to the increasing presence of local coquina outcrops (Field and Duane, 1974; Stauble and McNeill, 1985).

Clausner (1982) found that the shoals off the Cape cause wave refraction around the feature, creating a shadow zone that protects these finer-grained, flatly-sloping beaches from high energy waves. Sediment in this portion of the study area was characterized as calcareous quartzose sands, with coarser foreshore sands occurring near outcrops of the Anastasia Formation (Clausner, 1982). Morphology of the peninsula is dominated by a number of terraces aligned roughly parallel to the present coastline, which have been interpreted as forming during brief transgressions associated with the Wisconsinan glacial period (Field and Duane, 1974). The morphological pattern was interpreted as a series of seaward-building beach ridges (Figure 2-3; Field and Duane, 1974). Present coastal processes are maintaining the beaches and moving sand in a southward direction (Clausner, 1982). South of Port Canaveral, the shoreline rotates to a northwest-southeast orientation, characteristic of the general study area.

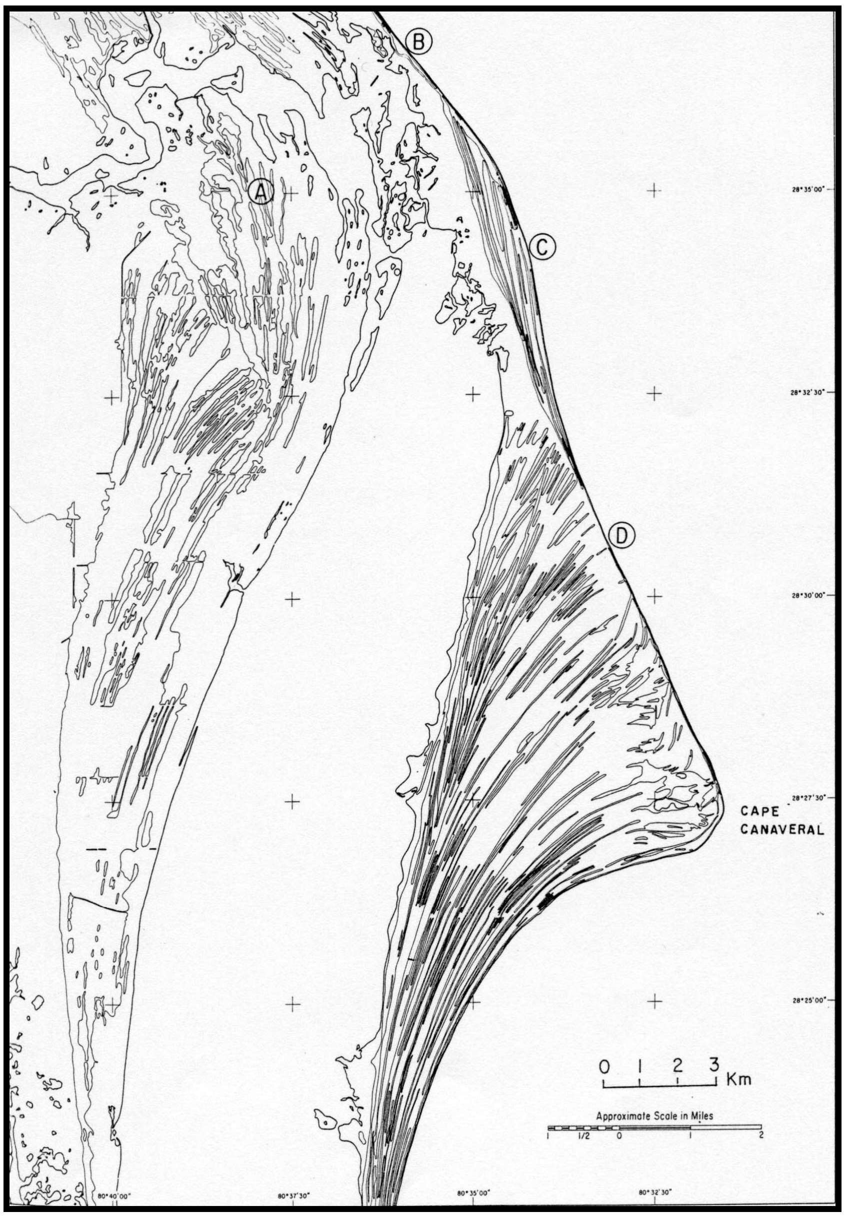

Figure 2-3. Canaveral Peninsula showing beach ridge orientations compiled from aerial photos and topographic maps (from Field and Duane, 1974).

The ocean shoreline from Port Canaveral south to Jupiter Inlet is composed of a continuous chain of five barrier islands that protect estuarine and coastal plain environments from direct wave attack. The islands are separated from each other and the mainland by five Federal entrances and the Intracoastal Waterway, which is made up of the Indian and Banana Rivers. Four of the five entrances within this section of coast are engineered, including Port Canaveral, Sebastian, Fort Pierce, and St. Lucie. Each of the entrances within the study area has been armored with rock jetties on both banks to control channel migration and maintain navigable entrance depths. Maintenance dredging also has been practiced periodically at all entrances to maintain channel navigability (Stauble and McNeill, 1985). Sand derived from dredging projects often is placed on south side beaches as nourishment material. Barrier islands comprising the chain in this region are relatively long and narrow, ranging from about 35 to 65 km in length and measuring on average less than 2 km in width. Foredunes are locally developed along various sections of the barrier islands, which prevents overwash and landward migration during storm events (Pilkey et al., 1984; Freedenberg et al., 1995b). The dunes have relatively low elevations, with heights generally ranging from about 2.5 to 3 m in most areas (Pilkey et al., 1984).

The outer coast along central east Florida is oriented primarily northwest-southeast, becoming north-south oriented within the southernmost portion of the project area. Beach sediments along this section of coast are composed primarily of medium- to coarse-grained sand with large quantities of carbonate mixed throughout (Meisburger and Duane, 1971). The median diameter of foreshore samples collected in this region averages about 0.43 mm (Figure 2-4; Hoenstine and Freedenberg, 1995). Beach sand is relatively well-sorted but contains large median size variations from one region to another. Quantities of shell material and alongshore processes controlling sediment distribution are the major factors influencing large size variations (Meisburger and Duane, 1971). All indurated sediments in the study area generally are assigned to the Anastasia Formation, which is regarded for the most part as Pleistocene in age but includes some recently cemented Holocene beach rock. The Anastasia underlies all modern beach sediments in the study area (Freedenberg et al., 1995b). State geological maps illustrate the general stratigraphy and surficial sediment classification for subaerial deposits within the study area (Figure 2-5). According to this classification scheme, most sediment comprising ocean beaches consist primarily of shelly sands and clays, with smaller areas of medium- to fine-grained sands and silts located on Cape Canaveral and south of St. Lucie Inlet. Stratigraphic maps of the area characterize the region as ranging from Pleistocene to Holocene age, with most of the coastline classified as Pleistocene or Pleistocene/Holocene.

2.1 OFFSHORE SEDIMENTARY ENVIRONMENT

Morphology of the continental margin offshore southeastern Florida reflects the influence of four separate shaping processes, including reef building during the Tertiary, deposition on the shelf in the littoral zones of the Pleistocene, erosion by the Florida Current, and deposition and shaping by bottom currents (Uchupi, 1969). Meisburger and Duane (1971) documented the Eocene and post-Eocene history within the study area as one of repeated invasions and retreats of the sea. Erosional unconformities and hiatuses in the Eocene column point to tectonic instability throughout that period. Analysis of seismic reflection profiles indicated an abrupt steepening of dip of some deep reflections, an apparent effect of a near-coast fault between Cape Canaveral and Fort Pierce (Meisburger and Duane, 1971). During the Pleistocene, central east Florida was alternately flooded and exposed to subaerial erosion, leaving a variable and sometimes complex series of sediment and erosional surfaces (Meisburger and Duane, 1971). During Pleistocene interglacial periods, marine sands were deposited in submerged areas and transgressive stratigraphic sequences were formed (Stauble and McNeill, 1985). The last major event was the advance of the Holocene sea across the upper continental slope and shelf, starting about 12,000 years ago and ending about 4,000 years ago (Curray, 1965; Milliman and Emery, 1968). Reworking of some marine sands deposited within interglacial periods has continued during the Holocene (Stauble and McNeill, 1985). Presently, a thick sedimentary section underlies the area, with Pleistocene sediments of the Anastasia Formation comprising much of the offshore subsurface sedimentary environment.

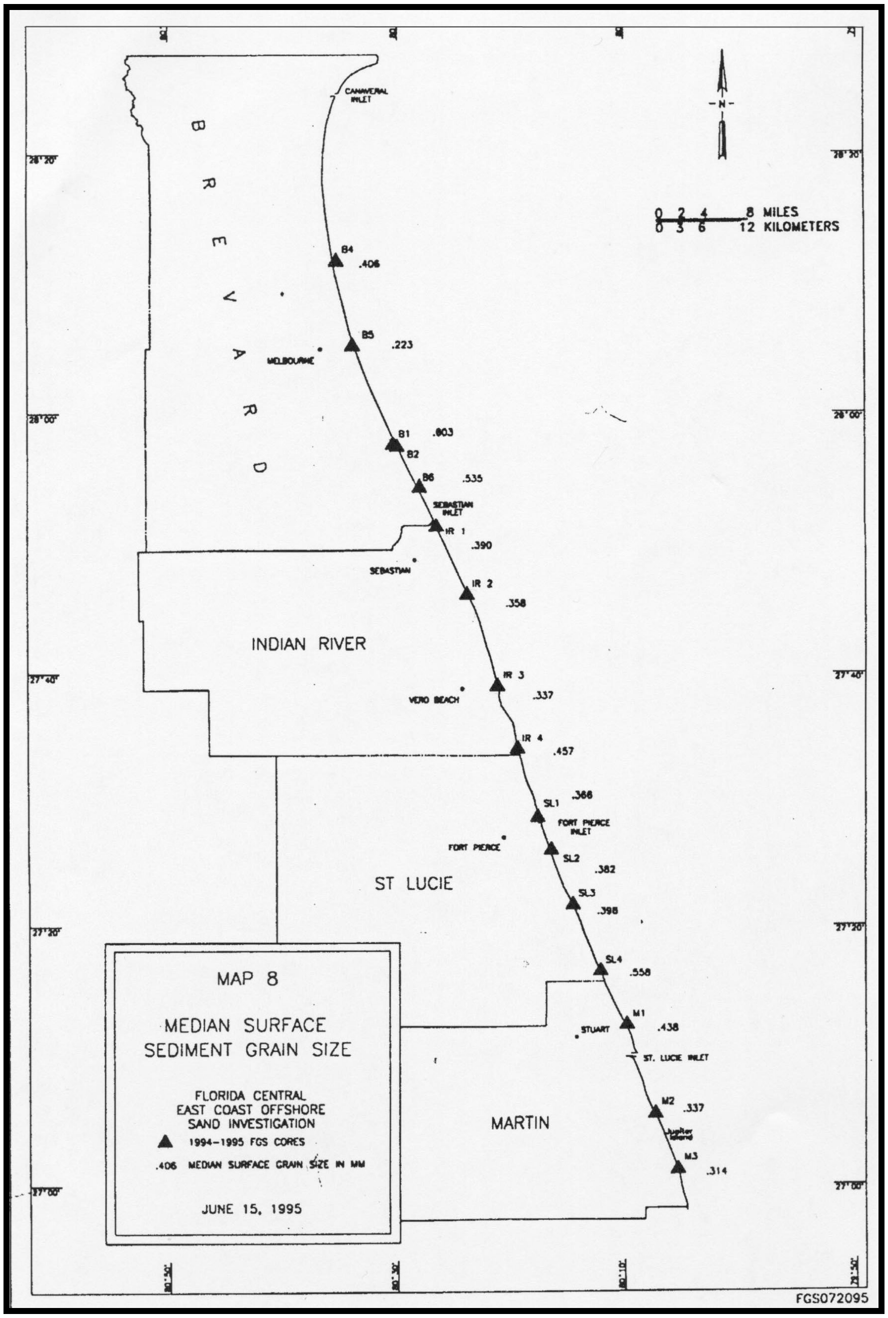

Figure 2-4. Median grain size of beach sediment collected between Brevard and Martin Counties (from Hoenstine and Freedenberg, 1995).

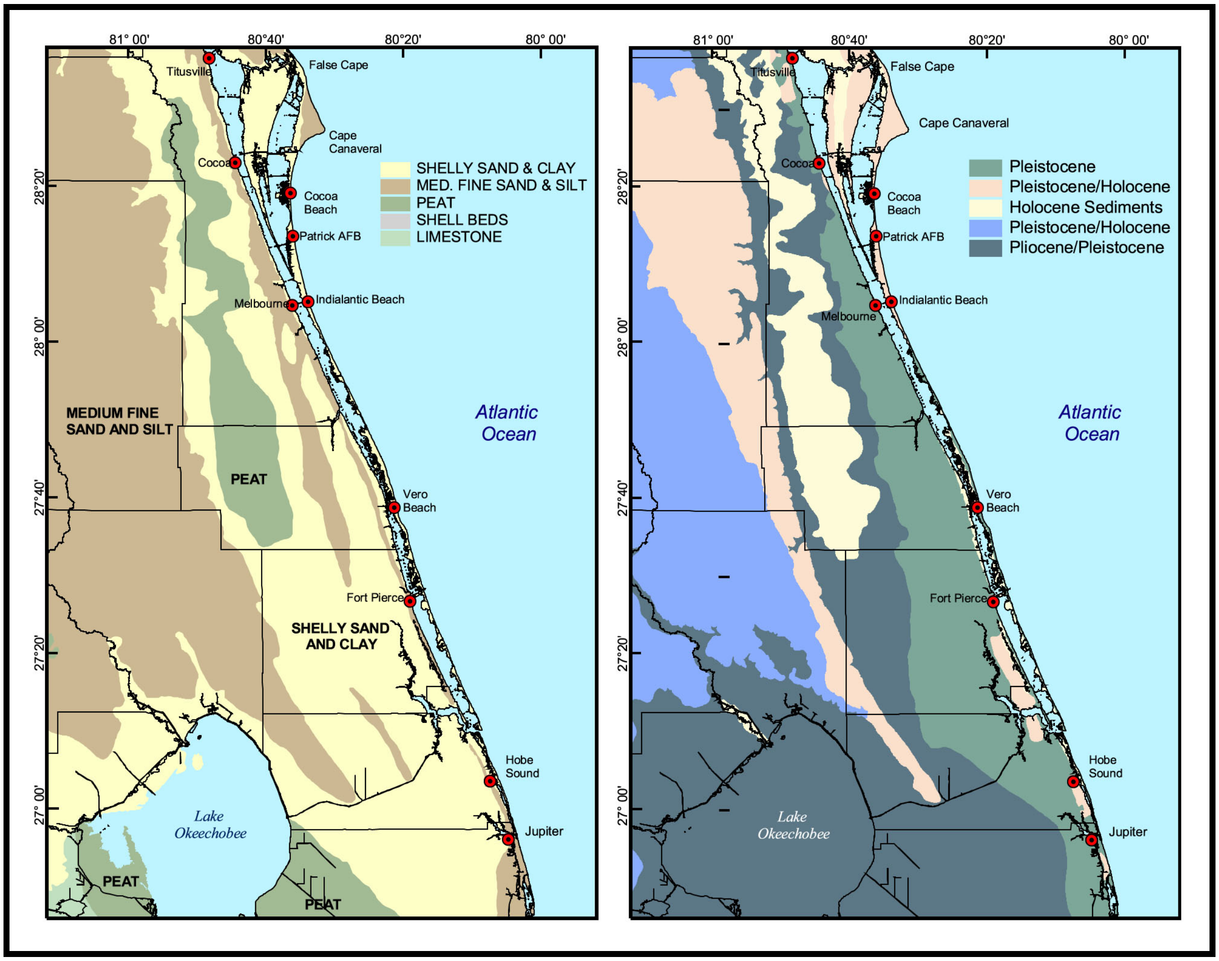

Figure 2-5. Surficial sediments and stratigraphy of central east Florida (adapted from the Florida Geological Survey digital data archive).

In some places, Anastasia rocks are overlain by quartzose sands of the Pamlico Formation, which locally attains thicknesses of 12 m but is usually much thinner (Meisburger and Duane, 1971).

Five physiographic provinces have been distinguished by Uchupi (1969) along the continental margin offshore eastern Florida based on bathymetric soundings. These provinces include the Florida Continental Shelf, the Florida-Hatteras Slope, the Straits of Florida, the Blake Plateau, and the Bahama Banks (Figure 2-6). The offshore portion of the study area is limited to the Florida Continental Shelf, which is the southernmost part of the East Coast Shelf. It is composed of strata lying at low angles and dipping generally easterly and southeasterly (Field and Duane, 1974). The continental shelf narrows dramatically from a maximum width of about 48 km near Cape Canaveral to a minimum of about 16 km in the southern extent of the study area as it merges with the Florida-Hatteras slope (Figure 2-6). This reduction in width is accompanied by a distinct increase in shelf steepness from north to south (Field and Duane, 1974). The Florida Continental Shelf has been classified into several morphologic zones, including an inner smooth zone extending from the shoreline out to a depth of about 16 m, a ridge zone (known as the Inner Shelf Plain) ranging from 16 to 40 m water depth, a second smooth zone (known as the Outer Shelf Plain) extending from 40 to 60 m water depth, and another deep ridge zone between -60 and -80 m (Uchupi, 1969). The inner ridge zone between 16 and 40 m water depth occurs in an area blanketed by relict terrigenous sands containing appreciable quantities of shell debris. Similar features also have been reported from other segments of the continental shelf off the U.S. east coast by Uchupi (1968). He has suggested that most of the ridges represent offshore bars formed during lower stands of sea level during the Pleistocene. He also suggested that some of the ridges may still be active at present, particularly during intense storms such as hurricanes. Ridges located within the outer ridge section at the shelf edge also are believed to be related to prior lower stands of sea level during the Pleistocene (Uchupi, 1969).

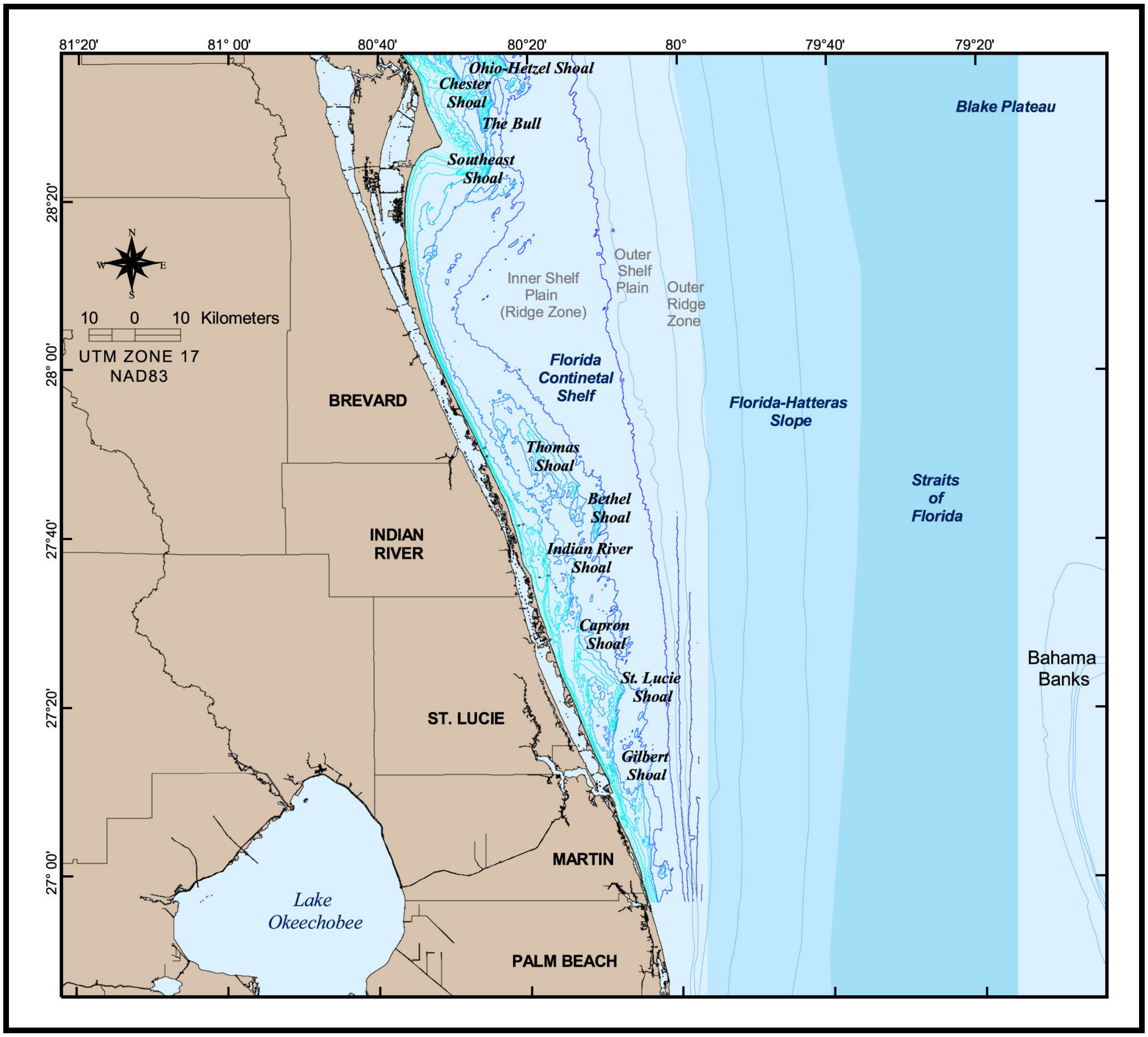

Figure 2-6. Physiographic provinces of the continental margin offshore central east Florida.

All sand resource areas defined for this study are located within the inner ridge portion of the continental shelf. Characteristics of the offshore sedimentary environment, specifically the numerous sand ridges found in this region, have been summarized by numerous investigators. Some of the more notable investigations that have been completed for the study area include early research performed as part of the Inner Continental Shelf Sediment and Structure (ICONS) Investigations completed by Meisburger and Duane (1971), Duane et al. (1972), and Field and Duane (1974), which characterized the morphology and sedimentary regime of linear sand shoals along the Florida Atlantic continental shelf. More recently, geological characterizations made by Stauble and McNeill (1985), Nocita et al. (1990), Amato (1993), Freedenberg et al. (1995b, 1997, 1999, 2000), and U.S. Army Corps of Engineers (USACE) (1999a) have added substantial detail to that obtained from early studies. The following sections use background information obtained from these sources in addition to recent sediment sampling to describe offshore deposits and their relationship to defined sand resource areas.

2.1.1 Seabed Morphology

The Florida Continental Shelf offshore central east Florida is characterized primarily by a well-developed shoreface zone, numerous cape-associated arcuate shoals, isolated or shoreface-attached linear sand ridges, and a gently sloping Outer Shelf Plain. These characteristics divide the shelf naturally into its major components, including the inner smooth zone associated with the shoreface region, the Inner Shelf Plain zone associated with sand shoals and ridges, and the Outer Shelf Plain. The most prominent geomorphic features throughout the region are offshore shoals and linear sand ridges, including Ohio-Hetzel and Chester Shoals in the north to Gilbert Shoal in the southern portion of the study area (Figure 2-6). Shoal morphology and frequency in this region varies considerably from north to south. Adjacent to Cape Canaveral, topography of the inner shelf is highly irregular, with large arcuate and isolated shoals extending southeast from False Cape and Cape Canaveral (Figure 2-7). South of the Canaveral shoal system, topography of the shelf becomes more subdued as it flattens south of Port Canaveral. From Sebastian Inlet south to Jupiter Inlet, shelf morphology again becomes more irregular, with numerous north-south trending linear shoreface-attached and isolated shoals dominating the structure of the shoreface and the inner shelf region (McBride, 1987).

The shoreface extends from the shoreline to about the 12-m depth contour. The character of this offshore zone varies considerably throughout the study area, as the influence of cape-associated and shoreface-attached linear shoals varies significantly. The shoreface is steepest north of Cape Canaveral, an area that has historically experienced relatively high rates of erosion due to south-directed littoral transport. South of this area and adjacent to Cape Canaveral, the shoreface becomes increasingly irregular as its configuration is interrupted by two shore-connected shoals. These two shoals, Southeast and Chester Shoals, merge from the shoreline on to the shoreface. South of Cape Canaveral to Sebastian Inlet, the shape of the shoreface becomes increasingly smooth and regular, making a gentle seaward dip and exhibiting relatively even contour spacing with minor irregularities out to the inner shelf plain. South of Sebastian Inlet, shoreface-attached linear shoals become more prevalent, creating a variable configuration seaward to the Inner Shelf Plain.

According to Meisburger and Duane (1971), surficial sediment comprising the upper shoreface (from the shoreline to about -6 m) was coarser, less well-sorted, and displayed greater variability than those found on the outer shoreface (from about 6 to 12 m water depth). Shallow nearshore sediment was composed of calcareous quartzose sand, with variations in size resulting from availability of a wide range of calcareous particle sizes (shell material). Bottom sediment of the lower shoreface was richer in quartz, finer, better sorted, and far more uniform in size than sediment found on the upper shoreface. Deeper shoreface deposits probably result from seaward transport of fine material winnowed from sand deposits in the high-energy surf zone (Meisburger and Duane, 1971).

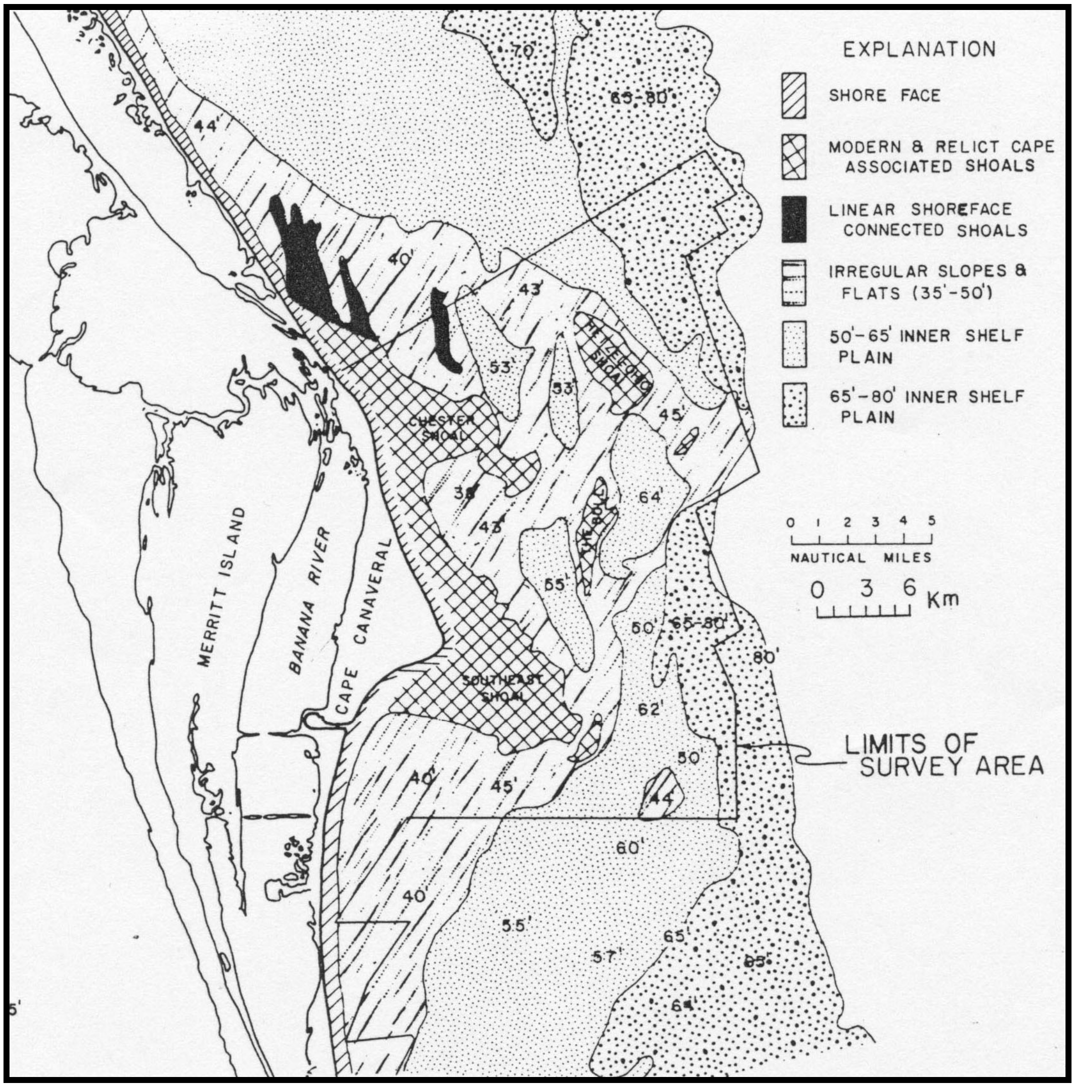

Figure 2-7. Morphological subdivisions of the Cape Canaveral Inner Continental Shelf. Soundings are from National Ocean Survey Chart 1245 (from Field and Duane, 1974).

Morphologic features on the Inner Shelf Plain consist of a series of platforms or step-like flats, gentle slopes leading from one flat to the next, and shoals (Meisburger and Duane, 1971). Inner Shelf Plain deposits contain considerable variation from north to south due to shoal morphology. Shoals within the northern extent of the study area are abundant and large, including cape-associated shoals trending southeast from Cape Canaveral and large isolated linear shoals immediately seaward of the shoal tips (Meisburger and Duane, 1971). Consolidated and unconsolidated ridges have been identified by previous investigations within this region. Consolidated ridges may represent former strandline deposits on the shelf edge. Large shoals, ridges, and channels exist along the shelf surface adjacent to the Cape from the shoreface to about 12 km offshore. The alignment of ridges parallels the cape shoreline and extends southeast from the foreland. The shoal system extending southeast from Cape Canaveral generally is very shallow, with depths ranging from about 4 to 12 m. Shoreface-attached shoals and the cape shoals are actively changing in configuration by modern nearshore processes. Analysis of shoal migration in this region shows them to be broadening and thickening (USACE, 1999a) and migrating to the south

(Byrnes and Kraus, 1999). Direct evidence of active reworking is recorded by sediment characteristics and bathymetric data (Field and Duane, 1974; Byrnes and Kraus, 1999).

South of Cape Canaveral, the Inner Shelf Plain is characterized by a gentle seaward inclination, a narrow depth range, and a general alignment parallel to the northwesterly trend of the shoreline. Between Port Canaveral and Sebastian Inlet, the inner shelf is lacking the variable shoal topography found to the north and south. South of Sebastian Inlet, shelf topography again becomes more complex. Shoal characteristics in this region have been well-studied and summarized by Duane et al. (1972) and Meisburger and Duane (1971). The southern shoal complex contains numerous shoreface-attached and isolated linear shoals with their long-axes lying predominantly north-south. Nearly all shoals are linear and have a north or northeasterly alignment, except for Thomas Shoal off Sebastian Inlet and an unnamed ridge between St. Lucie and Capron Shoals. These two shoals have a northwesterly alignment suggesting a different genetic process or time of formation. Most shoals in the study area are located about 12 to 14 km offshore, landward of the 20-m depth contour, and range in depth from about 8 to 14 m. Bethel Shoal is located further offshore, at a distance of about 18 km. Shoals tend to crest at about -6 to -10 m, with some of the smaller shoals cresting at about -15 m. Shoal profiles illustrate a smooth and regular surface, with symmetrical and asymmetrical cross-sectional form (Figure 2-8). Where asymmetry exists, the steeper flanks face southeast. Sediments comprising the shoals typically are well sorted biogenic medium- to coarse-grained sand with 15% to 30% quartz. Between the shoals, the seafloor is nearly flat and is covered by a layer of biogenic sand similar to that comprising the shoals. However, the sand tends to be more poorly sorted, more angular, and is highly bored by encrusting organisms. Many shoals visible on the seafloor exist seaward of the Federal-State Boundary, creating ideal locations for potential sand borrow sites for beach nourishment.

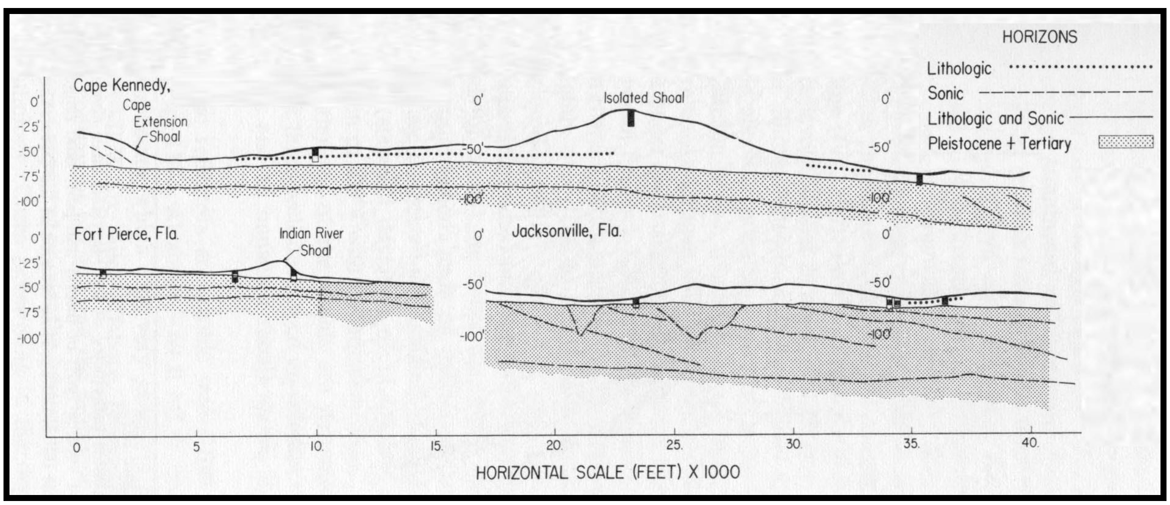

Figure 2-8. Shoal profiles offshore Cape Canaveral and Fort Pierce, FL (from Duane et al., 1972).

2.1.2 Surface Sediments

There is general agreement that surficial sediment on the shelf offshore central east Florida is composed primarily of well-sorted, medium-to-coarse quartzose calcareous sand that contains a high percentage of shell fragments (Meisburger and Duane, 1971; Field and Duane, 1974; Nocita et al., 1990; Amato, 1993). There are a number of sand rich areas along the shelf, with sand thicknesses generally related to shelf topography (thick under shoals and relatively thin under flats and swales) (Nocita et al., 1990). Sediment grain size generally increases to the south, with median grain size and the percentage of carbonate showing considerable variation from one area to the next. The increase in size and local variability are due to the presence of local coquina outcrops in this area. Field and Duane (1974) characterized surface sediment on the shelf adjacent to Cape Canaveral as well-sorted, medium-to-coarse quartzose calcareous sand that is presently being reworked and redistributed. They concluded that surficial sediment has been generated in part by biogenic activity and southerly littoral transport of eroded coastal materials, but that most sediment was derived from seafloor erosion of underlying Pleistocene deposits. Most erosion of the older weathered surface occurred during transgression, but physical and biological erosion are still active in some areas. At some locations, the Pleistocene surface crops out on the seafloor as ledges and rock surfaces (Field and Duane, 1974).

A study completed by Amato (1993) found that sand on the inner shelf north of Cape Canaveral locally contains up to 75% calcium carbonate, mostly in the form of shell debris (Figure 2-9). He concluded that sand was probably deposited by fluvial processes. Sand on the middle and outer shelf areas is mostly medium to coarse grained (Milliman, 1972). Amato (1993) estimated that at the Cape, shelf sand contains 25 to 50% carbonate that increases to greater than 75% southward and seaward. Nocita et al. (1990) completed a study of the area offshore Cape Canaveral for surface sediments and potential sand thicknesses. He concluded that offshore sand-rich areas roughly corresponded to shoal areas, and that virtually all of Southeast Shoal, with water depths greater than 10 m, was greater than 90% sand (Figure 2-10). Chester Shoal, the shore-attached shoal to the north of the Cape, as well as several isolated offshore shoals, were also sand-rich (Nocita et al., 1990). This study found that the gravel-rich areas were greatest in areas closest to shore north of Cape Canaveral, and that the only areas with significant amounts of mud-rich sediments were located south of Southeast Shoal (Figure 2-6). The USACE (1999a) collected sediment samples along Southeast Shoal within Sand Resource Area A1 and found that the median grain size of sediments ranged from 0.18 to 0.56 mm, for an average of 0.55 mm. Shell content in collected samples ranged from 34 to 53%, for an average of 43%.

Meisburger and Duane (1971) found that the dominant sediment type south of Cape Canaveral was primarily medium to very coarse, poorly sorted calcareous sand. Quartz was present, but its content ranged widely from a few percent to over 40%. Quartz sand occurs as a ubiquitous blanket over the inner shelf, covering low relief areas to about 1.5 m thick, with greater thickness over shoals. Deposit thickness ranged from a 0.5 to 5.0 m, with sand thickness exceeding 10 m in some areas. Meisburger and Duane (1971) attributed the source of most sediment particles found in cores offshore Fort Pierce to benthic biota. Quartz, the only noncarbonate particle present in significant quantity, was derived from the Piedmont Province because no primary quartz-bearing rocks crop out along the Florida Peninsula. Meisburger and Duane (1971) postulated that the origin of carbonate sediments in this region was from local shelled organisms or may have originated outside the area and subsequently entered as detrital sediments. A third possibility is that the skeletal fragments were reworked from older, underlying formations (Meisburger and Duane, 1971). Sediments of the Anastasia Formation are composed of a highly variable series of coquina, sand, and biogenic limestone deposits possibly representing depositional episodes throughout the Pleistocene (Meisburger and Duane, 1971).

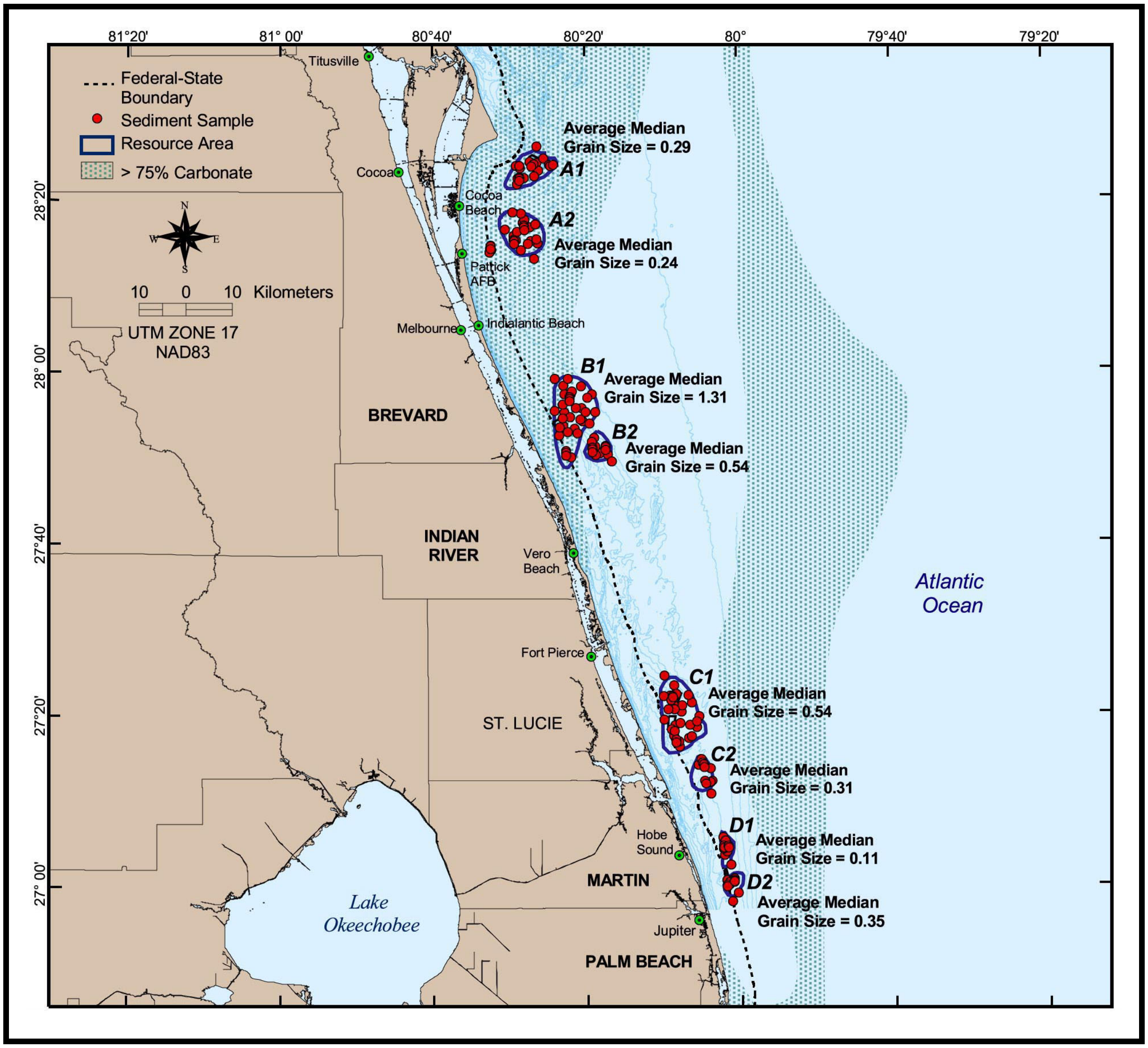

Figure 2-9. Sediment grab samples collected offshore central east Florida.

Grab samples were collected at each of the sand resource areas to provide additional information on surface sediment characteristics. Sample locations and average median grain size for each site are illustrated in Figure 2-9, along with areas determined by Amato (1993) as consisting of greater than 75% carbonate. Overall, the sediment distribution displayed by these samples was consistent with trends observed by previous investigators. The predominant sediment type found within the resource areas is medium- to coarse-grained sand, with five of the nine resource areas (A1, B2, C1, C2, and D2) indicating an average median grain size within either of these two categories. Four of these five resource areas contain proposed borrow sites. Each of these is located on sand shoals, consistent with sediment characterizations made by Duane et al. (1972) for shoal sedimentary composition.

Resource Areas A2 and D1 had the smallest average grain size, classifying these two regions as fine sand and very fine sand, respectively. Area D1 is classified as very fine sand (0.11 mm) and is located in the deepest water of all sand resource areas. Area A2 is classified as fine sand (0.24 mm) and is located within the gently sloping Inner Shelf Plain, lacking variable topography that tends to dominate other sand resource areas. Resource Area B1 has the largest median grain size (1.31 mm), classified as very coarse sand. The location of Area B1, offshore Sebastian Inlet, is within an area that has been defined by McLaren and Hill (2002) as consisting of a high percentage of carbonate. Although average median grain size for this resource area is larger than that calculated for borrow sites in other areas, sediment samples obtained within and immediately adjacent to the borrow site in Area B1 have an average median grain size of 0.6 mm. Overall, sediment size distribution illustrated by surface sediment samples demonstrated the dominance of medium- to coarse-grained sand along the central east Florida continental shelf, particularly associated with offshore shoals.

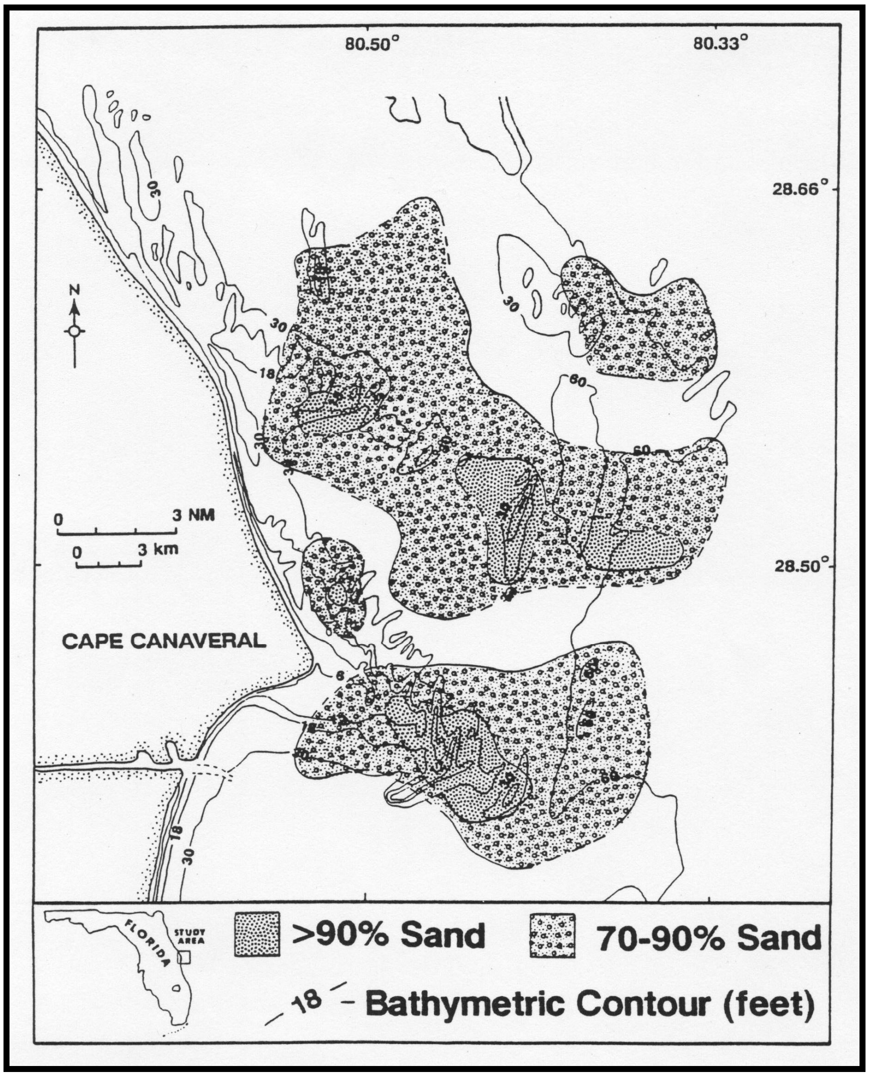

Figure 2-10. Distribution of sand-rich sediment in upper portion of shoals seaward of Cape Canaveral (from Nocita et al., 1990).

2.1.3 Subsurface Deposits

Numerous geological studies have been conducted within the study area to document continental shelf sedimentation processes and describe the regional character of shelf stratigraphy and sedimentology. Early investigations completed by the ICONS program

(Meisburger and Duane, 1971; Field and Duane, 1974) developed regional subsurface geological characterizations of the continental shelf adjacent to Cape Canaveral and offshore southern Brevard, Indian River, St. Lucie, and Martin Counties. Much of the work completed between southern Brevard and Martin counties was focused on the area adjacent to Fort Pierce Inlet. Recent studies completed by the FGS have built upon this early work and provided further detailed depictions of surficial and subsurface geology along the Florida Continental Shelf. The USACE (1999a) examined surface and subsurface sediments at Southeast Shoal within the borrow site in Area A1 to determined potential sediment thicknesses. Additionally, Duane et al. (1972) documented the shallow geology of nearshore and offshore sand ridges for determining the genesis of shoreface ridge deposits.

Field and Duane (1974) examined the geomorphology and sediment characteristics in the region offshore Cape Canaveral by collecting vibracores and high-resolution seismic data. The extent covered by seismic profiling generally fell outside the major offshore shoal seaward of the Cape. Nocita et al. (1990) designed an investigation of shore-attached shoals seaward of the Cape. The study included collecting surface sediment samples, vibracores, and seismic reflection profiles. Two sets of sediment samples, including a total of 84 vibracores and 140 surface samples, in addition to 174 km of seismic profiles, were collected to document the distribution of surface and subsurface sediments, especially those which might be desirable for the purposes of beach nourishment. Surface and subsurface sedimentary characteristics were determined and lateral extents and subsurface thicknesses of sand deposits on the shoals were estimated.

Shelf sedimentary deposits offshore Brevard to Palm Beach counties were evaluated by Meisburger and Duane (1971). The study primarily focused on the offshore area adjacent to Fort Pierce Inlet, but included an extensive section of the inner shelf using seismic reflection data. Seismic lines were very widely spaced and were used to determine the subsurface character on a regional scale. The study focused on determining suitable offshore sites for obtaining beach nourishment material and determined sand resource thicknesses at particular shoals.

An on-going multi-year cooperative study between the FGS and MMS has collected and analyzed surface and subsurface sediments offshore southern Brevard, Indian River, St. Lucie, and Martin counties to identify and characterize offshore sand deposits suitable for potential beach restoration efforts along adjacent beaches. As part of this effort, push cores, grab samples, subsurface acoustic profiles, and vibracores have been collected at beach and offshore sites. Results obtained to date have provided most of the subsurface data relevant to characterizing the sedimentary characteristics of offshore sand resource areas.

2.1.4 Sand Resource Areas

The resource potential of offshore sand deposits within the study area was documented using geological data from Meisburger and Duane (1971), Duane et al. (1972), Field and Duane (1974), Nocita et al. (1990), the USACE (1999a), and Freedenberg et al. (1995b, 1997, 1999, 2000b). Sand volume estimates for Resource Area A1 were determined by Field and Duane (1974), Nocita et al. (1990), and the USACE (1999a). Nocita et al. (1990) concluded that at least 3 m of suitable beach nourishment material is available across a wide area of the shoals. Freedenberg et al. (2000b) documented that appreciable amounts of sediment were available within Southeast Shoal (Figure 2-11). Vibracores collected along the southwest flank of Southeast Shoal, an extension of the

Canaveral Shoal deposit, recorded more than 90% sand-sized material for most of the feature (Nocita et al., 1990). Sand thicknesses obtained from cores indicated that about 6 m of suitable material was available across Southeast Shoal. A study completed by the USACE (1999a) collected 30 vibracores within the borrow site associated with Area A1. Sediment analysis indicated that the beach-quality sand deposit associated with the borrow site in this area was a minimum of 3 m thick and was greater than 4.5 m at most core locations. The sand is coarse relative to local beach sand and contains a significant shell fraction.

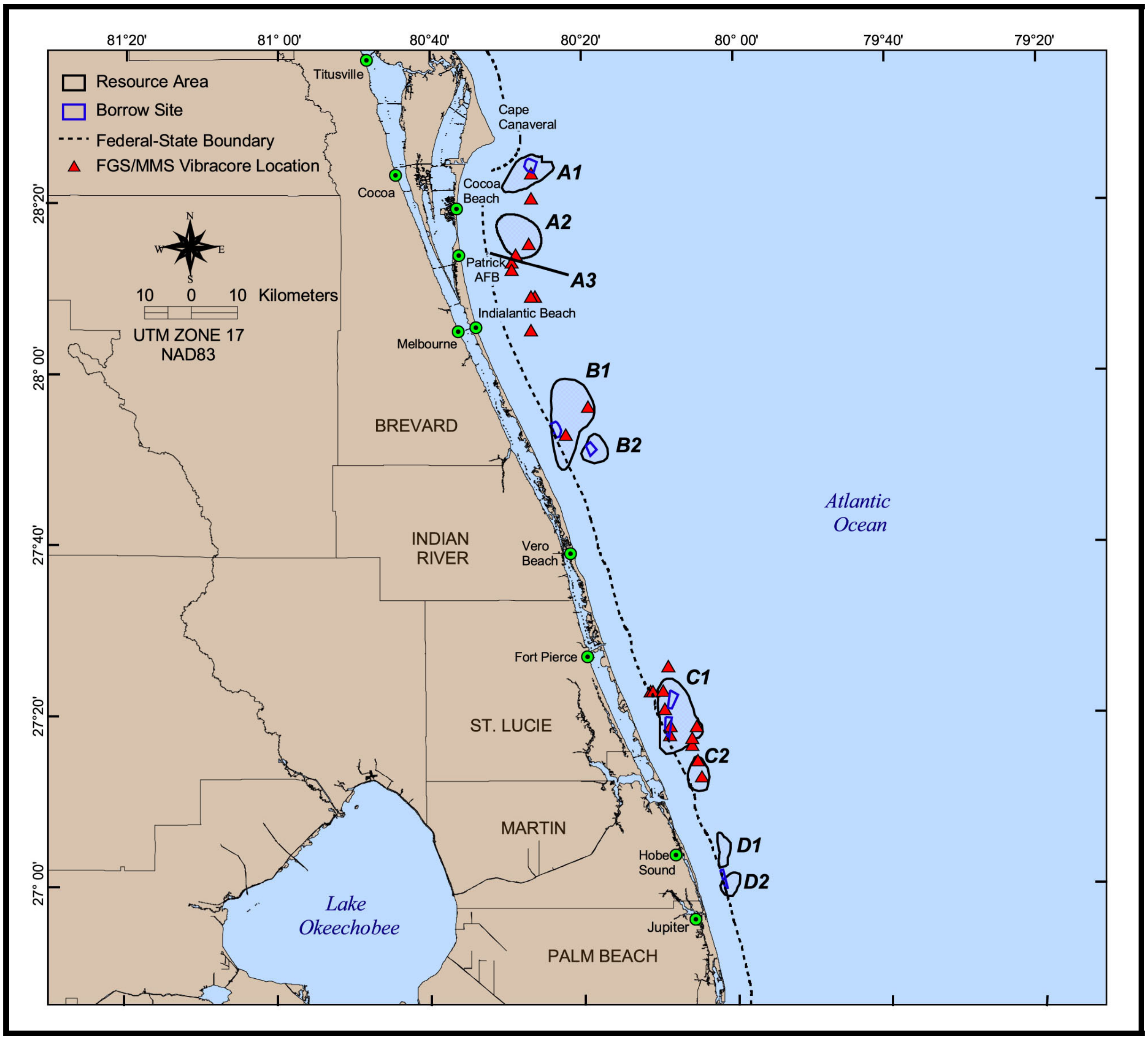

Figure 2-11. Vibracore locations offshore central east Florida (data from Freedenberg et al., 1999).

Sand resource areas situated to the south of Cape Canaveral are all located on or adjacent to linear sand shoals (Figure 2-11). Sand shoals within this area were identified by Meisburger and Duane (1971) as containing large quantities of suitable sediment for beach nourishment. Potential sand thickness estimates at Areas B1 and B2 were determined using vibracore data collected by the FGS and MMS. Two vibracores, VB-9 and VB-10 were collected along the flank of Thomas Shoal, and contained about 2 and 2.5 m of beach-quality restoration sand, respectively (Freedenberg et al., 1999). Both vibracores were collected within Area B1, which lies on the flank of the shoal and has a potential borrow site located immediately adjacent to the Federal-State boundary. The borrow site in Area B2 is located along the crest of the Thomas Shoal.

Sand volume estimates at Resource Areas C1 and C2 were determined using vibracore data collected by the FGS and MMS. Six vibracores were sampled within these areas with sediment thicknesses ranging from 3 and 7 m. Only Area C1 has potential borrow sites located along the crest of St. Lucie Shoal and defined as C1 north and C1 south. Two of the four vibracores from Area C1 were collected directly within Borrow Site C1 south, indicating 6 to 7 m of suitable sediment. Area C2, located along the northern flank of Gilbert Shoal, was characterized using two vibracores. Each core showed suitable sediment thicknesses of about 2 m.

Resource Areas D1 and D2 have not been characterized to date as part of the FGS/MMS cooperative agreement. Only Area D2 has been assigned a potential borrow site. Characteristics of this borrow site, including its location along a small ridge crest and the median grain size of 0.35 mm for surface sediments, indicated that it had good potential as a suitable borrow site. Relief of the shoal above the ambient shelf surface was used to define the thickness of sediment available for beach fill.

2.2 GENERAL CIRCULATION

Florida Current dominates circulation along the central east Florida continental shelf. However, wind-driven currents also play an important role. Unlike other shelf regions where density and tidal forces contribute substantially to circulation processes, the controlling parameter in the Florida Current area seems to be the lateral position of the frontal zone relative to the shelf; the closer the front, the greater the influence on local circulation.

The Florida Current is the local manifestation of the Gulf Stream, the intense western boundary current of the North Atlantic that transports heat north from the equator. The system narrows and intensifies between the southeast Florida shore and the Bahamas; this portion of the Gulf Stream is commonly known as the Florida Current. The axis of the Florida Current runs northward, east of the study area. Flow speeds can exceed 2.5 m/sec (Lee et al., 1985).

Circulation processes within the study area include spin-off eddies and meanders of the Florida Current, wind-driven currents, upwelling/downwelling dynamics, and tides. Other contributions may stem from shelf waves, inertial oscillations, and coastal inlet exchange. Shelf currents are aligned principally along isobaths; cross-shelf components are typically much weaker. Despite the presence of multiple forcing mechanisms, most current energy on the shelf can be related to subtidal variability (Lee and Mayer, 1977). The position of the Florida Current front is the principal control of subtidal shelf circulation from Miami to Cape Hatteras (Zantopp et al., 1987).

2.2.1 Florida Current and Eddies

The Florida Current frontal zone meanders laterally along the shelf break. Meanders can be caused by instability of the Florida Current, instabilities caused by topographic features, and variable wind stress that pushes the Florida Current axis onshore and offshore (Lee and Mayer, 1977). Meanders travel northward as waves; wave crests are onshore excursions of the front and troughs are offshore excursions (Zantopp et al., 1987). Horizontal velocity shear between the Florida Current and ambient shelf waters produces cyclonic ‘spin-off’ eddies along the western edge (Lee, 1975). Once formed, these eddies propagate northward along the shelf. Eddies have length scales of approximately 10 km in the east-west direction and 20 to 30 km in the north-south direction. Eddies form consistently, about once every 2 days to 2 weeks, depending on location and time of year (Lee, 1975; Lee and Mayer, 1977; Lee and Mooers, 1977; Lee and Atkinson, 1983; Santos et al., 1990). Spin-off eddies translate northward at speeds about 20 to 100 cm/sec (Lee and Mayer, 1977). Zantopp et al. (1987) tracked three eddies in summer of 1984 and reported translation speeds of 40 to 60 cm/sec. Swirl speeds within the eddy can be 100 cm/sec to the north and 50 cm/sec to the south (Lee and Mayer, 1977).

Eddies penetrate occasionally onto the inner shelf (depths less than 20 m). North of Cape Canaveral, where the shelf is relatively broad, Santos et al. (1990) showed that Gulf Stream effects were negligible at the 28-m isobath. Wind stress along the shelf dominated subtidal currents in the nearshore region. Gulf Stream effects became more pronounced at the 40-m isobath and dominated currents at the shelf break (75-m isobath). Lemming (1980) reported inner shelf currents at locations north of Cape Canaveral were highly consistent with winds. At Miami, where the shelf is quite narrow, Lee and Mayer (1977) found flow on the inner shelf markedly different than the outer shelf. At depths less than 10 m, inner shelf currents responded directly to wind stress, either northward or southward depending on wind direction, while variability on the outer shelf was due to eddy and Florida Current meander effects. Smith (1981) found that current variability on the narrow inner shelf (depths <10 m) near Fort Pierce was poorly correlated to wind stress, suggesting observed variability was likely a dynamic adjustment to Florida Current eddy intrusions.

Eddies also are important drivers of water mass exchange along the shelf, triggering upwelling events along the shelf throughout the year. Smith (1981, 1982, 1987) and Lee and Pietrafesa (1987) show intrusions of cooler water onto the shelf were inconsistent with Ekman-type wind stress, where winds push surface waters offshore and colder bottom waters upwell toward shore in response to a pressure deficit near shore. Rather, temperature and current variability were more consistent with eddy intrusion. Hsueh and O’Brien (1971) described how frictional forces between a steady alongshore current and the shelf create a cross-shore geostrophic imbalance, inducing onshore bottom flow, or upwelling. Colder waters, beneath the Florida Current, upwell and become entrained in spin-off eddies. The cyclonic eddies then mix horizontally with warmer Florida Current waters, especially on the leading edge of the meander, forming elongated filaments and shingles of the Florida Current along the shelf (Zantopp et al., 1987). Such mechanisms explain observed temperature and density variability within the study area as well as the important role eddies play as nutrient suppliers to coastal waters (Lee et al., 1991). Freshwater inputs, such as river runoff, have negligible impact on density along the Florida shelf (Lee and Pietrafesa, 1987).

2.2.2 Wind-Driven Currents and Upwelling

Seasonal wind variations contribute to shelf circulation indirectly by enhancing or repressing eddy-induced upwelling. From October to March, prevailing northeasterly winds create an onshore Ekman response and associated downwelling. Bottom currents oppose upwelling induced by Florida Current eddies. Hence, winter upwelling events are not as prolonged as during other months when predominant southeast winds create upwelling-favorable conditions, enhancing eddy-induced effects. Summer upwelling events can last for several weeks (Smith, 1983, 1987). Lee and Pietrafesa (1987) suggest that southwest winds drive localized upwelling due to the anomalous topographical feature at

Cape Canaveral. On the inner shelf, wind-driven subtidal variability also would be expected to have seasonal responses; winter conditions (northeast winds) would drive a southerly flow and summer conditions (southeast winds) would favor northerly currents.

2.2.3 Tidal Currents

Mayer et al. (1984) analyzed recent observations of the Florida Current around 27° latitude, and they reported tidal currents were responsible for approximately 16% of the total Florida Current variability. Diurnal tides were stronger than semi-diurnal tides, accounting for as much as 80% of the tidal energy. Peak tidal current speeds in water deeper than 300 m were about 12 cm/sec. Mayer et al. (1984) also suggested tidal oscillations were greatest on the western edge of the Florida Current. Lee and Mooers (1977) reported tides accounted for 10% to 25% of the Florida Current variability on the 300 m deep Miami Terrace area. Kielmann and Duing (1974) analyzed a 50-day record obtained offshore of Miami in about 300 m water depth, and tides accounted for about 25% of the along-axis current; diurnal components dominated. Cross-axis tides contained about 6% of the overall variance, again dominated by the diurnal constituent.

Extant literature provides less information on shelf tides within the study area. However, Smith (1982) measured oscillating tidal currents along the inner shelf off Fort Pierce at speeds approximately 10 cm/sec at the bottom. Cross-shelf tidal components rarely exceeded 10 cm/sec.

2.2.4 Storm-Generated Currents

Smith (1982) also described the response of shelf waters to Hurricane David (1979) based on near-bottom observations collected in 10 m water depth offshore Fort Pierce. Storm effects were characterized as a brief 1 m rise above normal high water, a doubling of peak current speeds along shore, and a marked decrease in bottom temperatures. Current speeds exceeded 60 cm/sec during the event compared to typical peak speeds of 30 cm/sec. Cross-shelf currents reached 30 cm/sec versus more typical speeds of 15 cm/sec. Near-surface currents at mid-shelf (depth ~26 m) measured 80 cm/sec versus typical peak currents of 40 cm/sec in the alongshore direction. Peak wind gusts during the event measured about 75 knots in southern Florida (National Hurricane Center archives).

2.2.5 Waves and Wave-Generated Currents

Wave height, period, and direction of approach, in addition to the magnitude and phasing of storm surge, are the most important dynamic factors influencing beach change in central east Florida. In most cases, buoy data are the preferred source of wave information because they represent actual measurements rather than hindcast information derived from large-scale models. However, very few sites along the U.S. east coast have wave measurement records of sufficient length to justify their use as a source of long-term information. McBride (1987) summarizes variations in wave height for the east coast of Florida using various USACE reports (Figure 2-12). Offshore central east Florida, sources of measured directional wave data include the Florida Coastal Data Network (CDN) (Wang et al., 1990) and various short-term deployments of individual gages (e.g., the 1991 University of Florida deployment of a wave gage offshore Jupiter Island [Harris, 1991]). However, the most comprehensive analysis of nearshore wave climate for central east Florida is by the USACE, Coastal and Hydraulics Laboratory, through wave hindcast studies (Hubertz et al., 1993). A description of nearshore wave characteristics at four USACE Wave Information Study (WIS) stations offshore the study area is presented in Section 4.1.1.1.

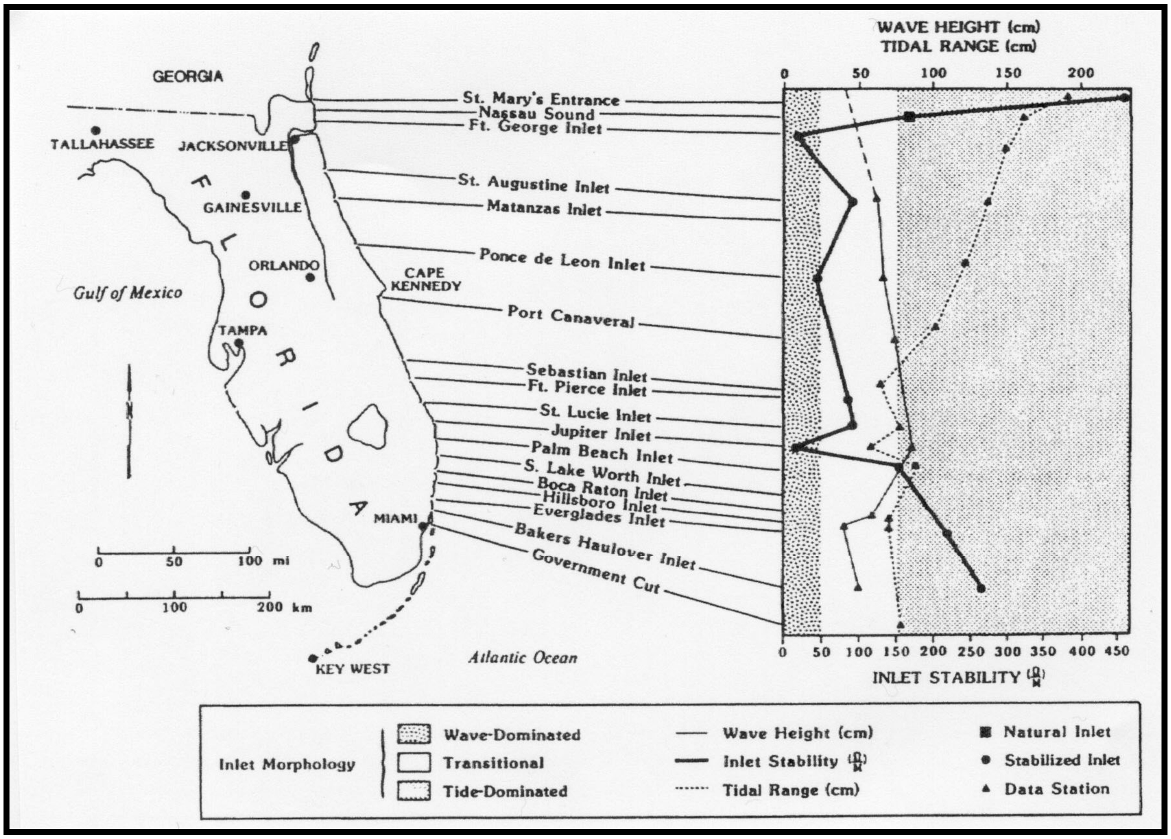

Figure 2-12. Plot of tidal range and wave height for the east coast of Florida (from McBride, 1987).

2.2.6 Nearshore Sediment Transport

As illustrated in Section 4.1.1.1, waves offshore central east Florida propagate principally from the east and northeast, producing net southerly transport of sand on beaches and in the nearshore (Duane et al., 1972; McBride, 1987; Dean, 1988; USACE, 1996). As illustrated in Figure 2-13, estimated net longshore sand transport along the east coast of Florida is quite variable, decreasing from approximately 600,000 yd^3/yr at Fernandina to about 10,000 yd^3/yr at Miami (Dean, 1988). Within the central east Florida study area, net southerly littoral drift is estimated at 350,000 yd^3/yr near Cape Canaveral (USACE, 1967, 1996; Kraus et al., 1999), decreasing to about 230,000 yd^3/yr at Jupiter Inlet (Duane et al., 1972; Dean, 1988). Substantial variations in estimated net longshore sand transport exist within this area as a function of dominant wave approach angle and shoreline orientation. Changes are illustrated by potential transport estimates computed for each wave modeling grid in Section 4.2.2 and historical shoreline change trends in Section 3.1.3.

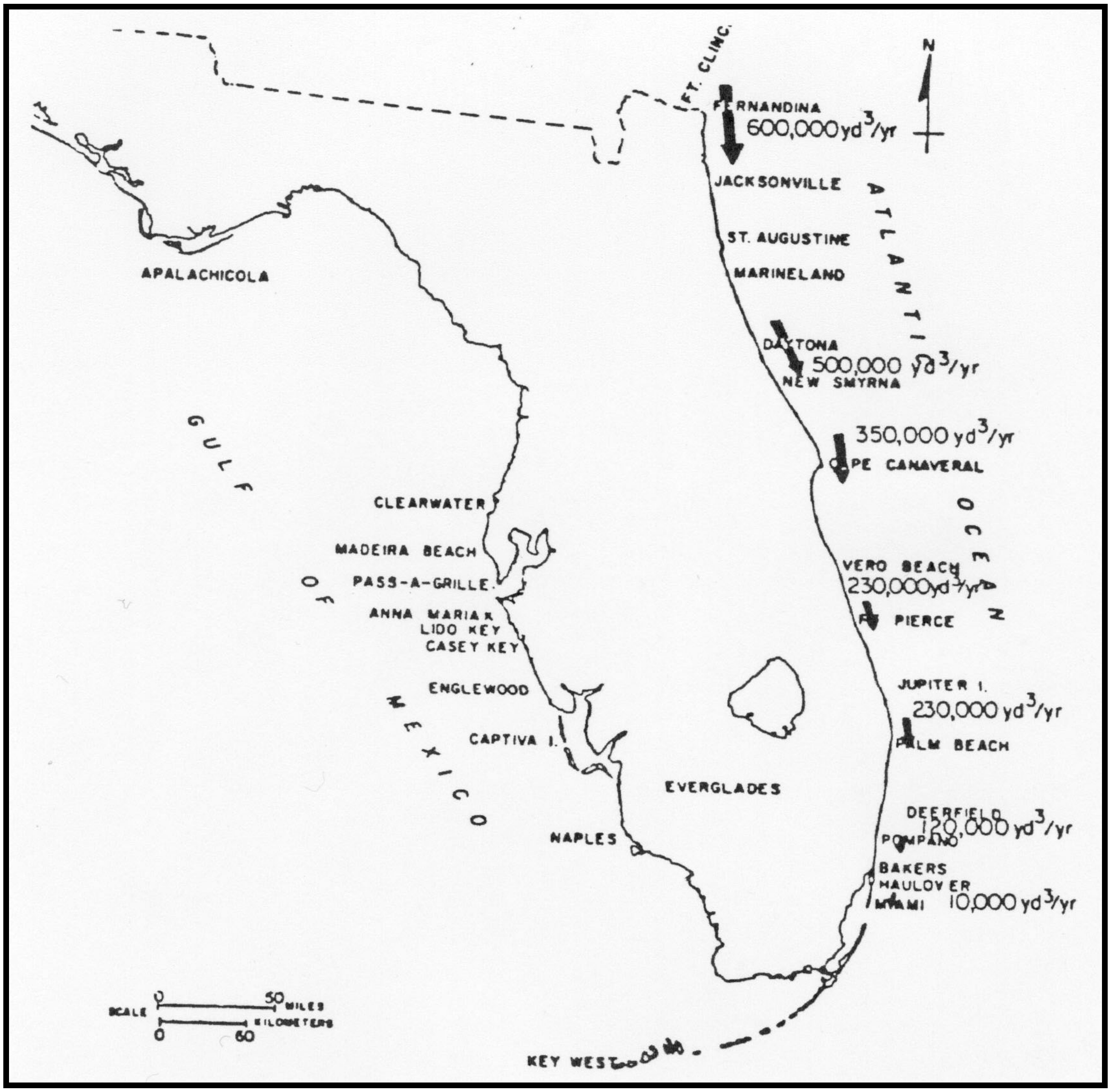

Figure 2-13. Estimates of net annual longshore sand transport along the east coast of Florida derived primarily from USACE documents (from Dean and O'Brien, 1987; Dean, 1988).

2.3 BIOLOGY

2.3.1 Benthic Environment

2.3.1.1 Soft Bottom

Infauna

Infaunal organisms inhabiting inner shelf waters offshore central east Florida predominantly consist of members of the major invertebrate groups that commonly inhabit sand bottom marine ecosystems, including crustaceans, echinoderms, mollusks, and polychaetous annelids. Infaunal assemblages that inhabit shelf waters of the study area include taxa common to much of the South Atlantic Bight (SAB) (Tenore, 1985; Weston, 1988; Barry A. Vittor & Associates, Inc., 1991, 2000), eastern Gulf of Mexico (Dames & Moore, 1979), and tropical areas of southern Florida and the Caribbean (Foster, 1971;

Camp et al., 1998). Generally, inner shelf infaunal assemblages are numerically dominated by polychaetes in terms of overall abundance and taxa (Day et al., 1971; Tenore, 1985; Weston, 1988; Barry A. Vittor & Associates, Inc., 1990, 1991, 2000). Other conspicuous members of the coastal infaunal community include amphipod crustaceans and bivalve mollusks. Infauna that inhabit sand bottoms in the study area are similar to marine assemblages in other regions in that they comprise assemblages that exhibit spatial and seasonal variability in their distributions.

East coast Florida waters are a transitional area between major zoogeographic zones. Macrofaunal assemblages inhabiting shelf sediments of the study area include a mixture of warm-temperate Carolinian and tropical Caribbean Province fauna (Briggs, 1974; Lyons, 1989), in addition to a significant endemic component (Camp et al., 1998). Several areas of the continental shelf along the southeastern U.S. have been suggested as transitions between temperate and tropical fauna, although areas of the Florida east coast have been proposed most often (Briggs, 1974). Briggs (1974) reviewed studies of species distributions along the U.S. east coast and determined that, based mostly on distributional data reported by others, the geographic location of a temperate/tropical faunal boundary is poorly defined, but that Cape Canaveral seemed to be centrally located within a broad north-south transition zone. However, Tenore (1985) found no latitudinal gradient of infaunal assemblage change on the inner continental shelf over a wide area of the SAB between Cape Fear, North Carolina and Daytona Beach, Florida, suggesting an absence of a geographically persistent transition area between faunal provinces across the region.

The extent of tropical fauna intrusion into more northerly latitudes is due primarily to the Gulf Stream (also referred to as the Florida Current), which brings warm water northward (Briggs, 1974). Convergence of biogeographic provinces in the region of Cape Canaveral largely is a result of interaction between various ocean currents that determine the latitudinal extent of relatively cool or warm water temperatures, creating an ecological barrier for members of the respective province assemblages. According to Lyons (1989), the Cape Canaveral area is characterized by the occurrence of tropical assemblages more than 40 km offshore, where the Gulf Stream flows, whereas much of the inshore fauna is associated with the warm temperate Carolinian Province. In the southern portion of the study area, near Jupiter Inlet, the inner edge of the Gulf Stream is usually less than 10 km offshore. In this area, for example, there is a marked increase of tropical mollusks on the inner shelf (Lyons, 1989).

Many of the most abundant infauna in the study area are among the numerical dominants across a broader geographic area. Tenore (1985) found that polychaetes were numerical dominants over a wide area of the SAB, accounting for over half of the total overall abundance. There was no obvious numerical dominance of any taxon that persisted seasonally in the SAB. Of the most abundant species, only 18 taxa comprised more than 0.2% of the total infaunal density at all stations in at least one season for the SAB study, including but not limited to the polychaetes *Spiophanes bombyx*, *Parapionosyllis longicirrata*, *Spio pettiboneae*, *Exogone lourei*, *Prionospio cristata*, *Protodorvillea kefersteini*, and *Goniadides carolinae*, and the cumacean *Oxyurostylis smithi*. Many of these numerically dominant taxa also are common in the Caribbean, for example, the polychaetes *S. bombyx*, *S. pettiboneae*, and *P. cristata* (Foster, 1971). Offshore Hutchinson Island, Florida, in the southern part of the study area, Lyons (1989) found that most mollusks collected from inner shelf sediments are broadly ranging, eurythermal species that occur from Cape Hatteras, North Carolina to Brazil.

Relatively few open shelf benthic studies have been conducted in the study area. The Canaveral Harbor Ocean Dredged Material Disposal Site (ODMDS) was investigated during June 1990 as part of a monitoring study of that site (Barry A. Vittor & Associates, Inc., 1991). Benthic samples were collected from 15 offshore stations at water depths of 12 to 18 m. Sand stations outside the ODMDS commonly yielded great abundances of the amphipod *Acanthohaustorius pansus*, archiannelid *Polygordius*, bivalve *Ervilia concentrica*, and polychaetes *Goniadides carolinae* and *Prionospio cristata*. More recently, the Fort Pierce ODMDS was investigated as part of a monitoring study (Barry A. Vittor & Associates, Inc., 2000). Three benthic monitoring stations were located within the ODMDS and nine stations were located just outside this area, ranging in depth from 12 to 16 m. Polychaetes were the most numerous organisms (37.8% of the total assemblage), followed by amphipod, decapod, and isopod crustaceans (29.4%), and gastropod (12.9%) and bivalve (10.2%) mollusks. Overall, the numerically dominant taxa were the polychaetes *Goniadides carolinae* (15.9% of the total number of individuals) and *Protodorvillea kefersteini* (7.0%), and non-identified oligochaetes (5.4%) and rhynchocoels (5.3%). Other taxa collected from all 12 stations included the arthropod *Maera caroliniana*, bivalves *Crassinella lunulata* and *Crassinella martinicensis*, polychaete *Heteropodarke formalis*, and gastropod *Caecum imbricatum* (Barry A. Vittor & Associates, Inc., 2000).

Infaunal populations that comprise open shelf benthic communities are affected by abiotic environmental parameters, resulting in both seasonal and spatial variability in their distribution and abundance. Shallow coastal waters are characterized by a variety of environments having great diurnal, seasonal, and annual fluctuations in their chemical, hydrographic, and physical properties. Distributions and abundances of benthic invertebrates are regulated at a basic level by these physical environmental forces.

Temporal variation in population abundance may be a result of response to proximal environmental variability or due ultimately to the life history patterns of individual species. Seasonality of macrobenthic assemblages inhabiting open shelf sediments has been noted in numerous investigations (e.g., Frankenberg and Leiper, 1977; Flint and Holland, 1980; Schaffner and Boesch, 1982; Weston, 1988; Byrnes et al., 1999). Patterns of seasonal reproductive periodicity in marine systems apparently are related to ambient climatic conditions, primarily temperature, for most marine invertebrates (Sastry, 1978). Reproduction is more or less continuous at deeper shelf depths (Warwick, 1980), where greater environmental stability promotes seasonal persistence of outer shelf infauna (Schaffner and Boesch, 1982). Camp et al. (1977) found a transient arthropod assemblage on the inner shelf offshore eastern Florida and suggested that the high rate of species turnover was at least partially due to the area being within the temperate-tropical transition zone.

An absence of temporal patterns of abundance for some macrobenthic species in many cases is related to reproductive strategies. Transitional infaunal species that do not emerge necessarily on a seasonal basis often colonize an area because of intermittent conditions that are favorable for reproduction. Opportunistic species generally are tolerant to fluxes within their environment, but more importantly they are early and successful primary colonists due to their reproductive capacity and dispersal ability (Grassle and Grassle, 1974). These species often undergo eruptive population peaks, depending on their adaptive ability to withstand varying environmental conditions, and can exploit an open niche while avoiding competitive interaction (Boesch, 1977). Because habitat availability often is the result of random perturbations of the environment, such as significant riverine outflow due to flooding, the appearance of these taxa often occurs in tandem with such episodes. For other, non-opportunistic species inhabiting marine soft sediments, a lack of temporal patterns of abundance may indicate simply that seasonal patterns of variability do not exist for these species (Pearce et al., 1976).

In addition to temporal differences in benthic assemblage composition, conspicuous spatial variability often is evident in the distributions of populations inhabiting open shelf sediments. Spatially variable environmental parameters such as hydrography, water depth, and sediment type influence benthic assemblage composition and the extent of numerical dominance of those assemblages by various infaunal populations.

Changes in infaunal assemblage composition along broad depth gradients have been noted in several studies of shelf ecosystems. Day et al. (1971) determined the distribution of infauna along a depth gradient from the beach zone to the edge of the continental shelf off Cape Lookout, North Carolina and found four subtidal zones delineated at increasing depth intervals. The turbulent zone included the inner shelf between 3- and 20-m depths, and corresponds with the location of the present study. The most common taxa of the turbulent zone were best represented at the 20-m depth station (Day et al., 1971). Tenore (1985) and Harper (1991) both reported a transition between inner shelf and continental slope fauna of the SAB and northern Gulf of Mexico, respectively. An approximate depth of 37 m is thought to be a transition between the fauna of shallow coastal zones and those of intermediate and deeper shelf zones offshore Florida (Camp et al., 1998).

Although there is a negative correlation between infaunal abundance and water depth, it is unclear whether such faunal distributions are affected mostly by absolute water depth, or whether depth-related factors such as hydrology, sedimentary regime, and seasonality override any effects of sediment particle size and type on infaunal assemblages. The effect of water depth on benthic assemblages may in some cases be defined more precisely as an effect of depth-related environmental factors, including physical parameters that vary with increasing depth, such as current regime, dissolved oxygen, sedimentary regime, and temperature. Surficial sediments tend to be well sorted at shallow depths, due primarily to the mixing of shelf waters by storms. Moreover, inner shelf waters generally are less depositional in nature than outer shelf or slope waters due to a dynamic current regime near the bottom, although shallow areas affected by estuarine outflow may experience episodic deposition of fine materials, which can influence benthic community structure.

Although some descriptions of depth-related differences in benthic assemblages have encompassed geographically broad areas (Day et al., 1971; Flint and Holland, 1980; Tenore, 1985), local variability in bathymetric relief can result in habitat heterogeneity within an area of relatively minor differences of absolute depth. Trough features, especially those that are bathymetrically abrupt, can dissipate current flow along the substratum surface, resulting in deposition of fine materials, including organic material. Presence of fine sediments and organics in bathymetric depressions can support benthic assemblages that are distinct from nearby areas without depressions (Boesch, 1972; Lyons, 1989; Barry A. Vittor & Associates, Inc., 1999).

Previous sampling efforts in open shelf waters have demonstrated the importance of sediment type in determining infaunal population densities. Wigley and Theroux (1981) summarized the relationship between sediment type and infaunal abundance. Coarse-grained sediments generally support the greatest numbers of infauna, while fine-grained sediments support the least. Amphipods are found in all sedimentary habitats, although densities are greatest in sand-gravel and sand habitats. Generally, bivalve densities are greatest in sand-shell sediments and decrease with increasing sediment particle size, although shell fragment habitats can support moderately high bivalve numbers. Gravel bottoms support the lowest densities of bivalves. Polychaetes occur in all sediment types, although abundances are greater in sand and gravel bottoms than in silt-clay habitats (Wigley and Theroux, 1981).

Lyons (1989) found that mollusk species abundance and assemblage composition were related to sediment type in inner shelf waters offshore Hutchinson Island, Florida. He found four species-sediment groups: 1) hard-packed, fine to very fine sands supported relatively few species or individuals; 2) well-sorted, medium-grained sands at an offshore shoal supported relatively few species but yielded many specimens; 3) poorly sorted, coarse to very coarse sediments in an offshore trough feature yielded twice as many mollusk species as did shoal sediments, but the number of individuals was similar to that found on the shoal; and 4) poorly sorted trough sediments of shell, gravel, and mud supported more species and many more individuals than any of the other three sediment types (Lyons, 1989).

Not only do sediment particle size and type influence faunal densities, they have a strong effect on the species composition of benthic assemblages (Sanders, 1958; Young and Rhoads, 1971; Pearce et al., 1981; Weston, 1988; Chang et al., 1992; Byrnes et al., 1999). Although many infaunal species occur across a range of sediment types, most infaunal taxa tend to predominate in specific sedimentary habitats.

Infaunal assemblages are composed of taxa that are adapted to particular sedimentary habitats through differences in behavioral, morphological, physiological, and reproductive characteristics. During the Canaveral Harbor ODMDS study (Barry A. Vittor & Associates, Inc., 1991), sand stations outside the ODMDS commonly yielded great abundances of the amphipod *Acanthohaustorius* sp. H, archiannelid *Polygordius*, bivalve *Ervilia concentrica*, and polychaetes *Goniadides carolinae* and *Prionospio cristata*. This sand assemblage was different from a silty sand assemblage collected inside the ODMDS and was numerically dominated by deposit feeders, including the bivalves *Abra aequalis*, *Diplodonta semiaspera*, *Lucina multilineata*, *Mysella planulata*, and *Tellina versicolor*, and polychaetes *Scoletoma verrilli*, *Magelona* sp. H, and *Paraprionospio pinnata*.

Fine-textured sediments are generally characteristic of depositional environments, where occluded interstitial space and accumulated organic material supports surface and subsurface deposit-feeding burrowers. All marine sediments are anoxic at some depth below the sediment-water interface, and the depth of oxygen penetration generally varies with sediment type. In very fine sediments, occlusion of interstitial space limits the depth of oxygen diffusion to a few millimeters into the sediment (Revsbech et al., 1980). Environments with more shallow penetration of dissolved oxygen tend to support deposit-feeding taxa that are able to maintain some form of hydrologic contact with the sediment-water interface, via the manufacture of tubes or construction of irrigating burrows. Coarse sediments in high water current habitats, where organic particles are maintained in suspension in the water column, favor the occurrence of suspension-feeding taxa that strain food particles from the water column and facilitate feeding by carnivorous taxa that consume organisms occupying interstitial spaces (Fauchald and Jumars, 1979). Different sedimentary habitats support particular infaunal assemblages that tend to vary across time.

Epifauna

Many numerically dominant epifauna that inhabit inner shelf waters may more precisely be described as epibenthic, especially gastropods and decapods, although many of these taxa routinely are collected along with infauna when grab samplers are used. For example, certain epifaunal taxa, such as lady crabs (*Ovalipes* spp.), commonly burrow deeply into sediments, and adaptive behaviors of this type can complicate efforts to categorize such taxa into a specific, lifestyle-based, invertebrate group. In addition, many bivalves are effectively sampled using either a trawl or grab method. Given this dilemma of ecological classification, however, the taxa discussed below commonly are collected in trawl samplers and, for the sake of comparison and consistency with previous investigations, herein are considered epifauna.

Common epifaunal invertebrates occurring on open shelf bottoms offshore central east Florida include calico scallop (*Argopecten gibbus*), calico box crab (*Hepatus epheliticus*), iridescent swimming crab (*Portunus gibbesii*), brown shrimp (*Farfantepenaeus aztecus*), white shrimp (*Litopenaeus setiferus*), striped sea star (*Luidia clathrata*), and arrowhead sand dollar (*Encope michelini*) (Continental Shelf Associates, Inc., 1987). Wenner and Read (1982) reported on decapod crustaceans collected by trawl over a wide area of the SAB between Cape Fear, North Carolina and Cape Canaveral, Florida and found that site and species group distributions were related to depth. Moreover, depth related changes in groups were altered very little seasonally. Species groups consisted of an inner shelf assemblage, an open shelf assemblage, and an upper slope assemblage. As with infaunal invertebrates, epifaunal populations have distributions limited by depth-related variability of temperature and sedimentary habitat (Cerame-Vivas and Gray, 1966; Wenner and Read, 1982). Wenner and Read (1982) found an inner shelf assemblage that was numerically dominated by roughneck shrimp (*Rimapenaeus constrictus*), iridescent and blotched swimming crabs (*P. gibbesii and P. spinimanus*, respectively), and coarsehand lady crab (*Ovalipes stephensoni*).

Despite the fact that the area offshore eastern Florida is recognized as a zone of convergence of distinct faunal provinces (Briggs, 1974), most common epifauna in the study area are distributed over a wider geographic range. Striped sea star (*L. clathrata*) occurs in Atlantic waters from New Jersey coastal waters to Brazil (Downey, 1973). The sand dollar *Mellita quinquiesperforata*, a shallow water species, is another widely distributed taxon that occurs along most of the U.S. east coast south to the Brazilian coast (Serafy and Fell, 1985) and is often found in great numbers on sandy inner shelf areas (Day et al., 1971). The sand dollar *Encope michelini* occurs from Cape Hatteras to the southern tip of Florida and throughout the Gulf of Mexico (Hendler et al., 1995). Iridescent swimming crab (*P. gibbesii*) occurs from Massachusetts through the Gulf of Mexico and south to French Guiana, and the calico box crab (*Hepatus epheliticus*) is distributed from Chesapeake Bay to the Caribbean (Abele and Kim, 1986). Brown and white shrimps (*F. aztecus* and *L. setiferus*, respectively) occur as far north as Massachusetts and New York, respectively (Abele and Kim, 1986). Roughneck shrimp (*R. constrictus*) occurs from Chesapeake Bay (Virginia) to Brazil (Chace, 1972).

Certain epifauna are associated primarily with particular sedimentary habitats (Wigley and Theroux, 1981). Gastropod densities generally are greatest in areas of coarse sand and gravel. Coarse sediments are more suitable for locomotion by broad-footed benthic mollusks than are fine sediments, which are relatively unstable. Lyons (1989) found that certain mollusk species were most abundant in an offshore trough feature with poorly sorted sediments, whereas other mollusks were abundant on an offshore shoal that had well-sorted, coarse sediments. Decapods generally are found in areas of gravel and shell, although species such as *Crangon septemspinosa* tend to occur in areas of sand and the crab *Cancer irroratus* inhabits a variety of sediment types. Wenner and Read (1982) suggested that the combination of extremely variable sediments and temperatures may be sufficient to cause marked zonation between decapod assemblages on the outer shelf. Camp et al. (1977) collected inner shelf decapods offshore Hutchinson Island, Florida and found that an offshore sand shoal was numerically dominated by roughneck shrimp (*Rimapenaeus constrictus*), while an adjacent trough feature predominantly supported portunid crabs. Sand dollars such as *M. quinquiesperforata* most commonly are associated with sand habitats. Brittle stars are most common in silty sand, probably due to greater efficiency of burrowing in finer sediments. Sea stars tend to be distributed across a range of sediments, from shelly sand to silt habitats (Wigley and Theroux, 1981).

Demersal Fishes

Ichthyofauna of eastern Florida is one of the most diverse and complex in the Western Atlantic. This high diversity is the consequence of environmental and biogeographic factors operating on various spatial and temporal scales (Gilmore, 1995, 2001). The primary environmental factor influencing fish distribution in the region is water temperature. Although the Gulf Stream current ameliorates water temperatures on the shelf throughout the region encompassed by the sand resource areas, atmospheric cooling and periodic upwellings also affect local water temperatures and in turn dictate the distribution of fishes. Seasonal drops in temperature affect inshore and coastal waters and limit the distribution of tropical species in inshore waters to about Sebastian, Florida (winter sea surface temperatures seldom fall below 20ºC south of 27º50’) (Gilmore et al., 1978). Water temperatures on the outer shelf can decline rapidly as a result of periodic upwellings that originate along the shelf break (Atkinson and Targett, 1983; Smith, 1983; Pitts, 1999). The interplay between atmospheric cooling in shallow waters and upwelling cold water intrusions on the outer shelf results in a limited band of suitable water temperature in 18 to 55 m depths (Miller and Richards, 1979). A result of the varying temperature patterns in the region encompassed by the sand resource areas is that local assemblages are composed of species with differing thermal preferences and tolerances. Species inhabiting the region are usually grouped by their relative temperature tolerance into tropical, subtropical, and warm-temperate (Miller and Richards, 1979), or more detailed variations of these general categories (Gilmore, 1995).

Overlap between tropical, subtropical, and warm-temperate faunas underlies the transitional nature of the region’s biogeography (Gilmore, 1995, 2001). In northern portions of the study area, near Sand Resource Areas A1, A2, and A3, warm-temperate species are more common and reach peak abundance in that region. At the southern end of the region, near Areas D1 and D2, more tropical species are present (Briggs, 1974; Gilmore, 1995). Consequently, the resulting ichthyofauna is composed of species with differing ecological and evolutionary histories that can be subdivided into several assemblages and eco-regions (Gilmore, 2001). This report describes fishes inhabiting waters of the study area by dividing the ichthyofauna into a demersal soft bottom assemblage (see below in this section), a demersal hard bottom assemblage (Section 2.3.1.2), and a pelagic assemblage (Section 2.3.2.1).

The demersal soft bottom fish assemblage that inhabits the open shelf off eastern Florida is composed of 213 species and 53 families (Gilmore et al., 1981; Gilmore, 2001).

The most speciose families include skates (Rajiidae), stingrays (Dasyatidae), torpedo rays (Torpedinidae), left-eye flounders (Bothidae), soles (Soleidae), cusk-eels (Ophidiidae), and searobins (Triglidae). Numerically abundant demersal fishes present on the open shelf include croakers, drums, and seatrouts (all three being sciaenids) and porgies (sparids).

As with most fishes, members of the eastern Florida demersal assemblage are distributed variably across space and time. Broad patterns are evident along cross shelf (bathymetic) and latitudinal axes as species segregate in recognizable assemblages. In the shallowest water depths, the surf zone, the demersal fish assemblage is characterized by kingfishes (*Menticirrhus* spp.), sand drum (*Umbrina coroides*), threadfins (*Polydactylus* spp.), and others (Peters and Nelson, 1987).

In shelf waters beyond the surf zone, the demersal assemblage is generally more diverse. The most comprehensive surveys of the eastern Florida demersal soft bottom assemblage have been conducted around Cape Canaveral and to the north using bottom trawl sampling gear (Anderson and Gehringer, 1965; Strushaker, 1969; Wenner and Sedberry, 1989). There has been very little information gathered on demersal soft bottom fishes of the study area. Certainly the smaller shelf width and higher proportion of hard bottom in the southern part have been deterrents to bottom trawling. In the northern portion of the project region, near Sand Resource Areas A1, A2, and A3, the demersal ichthyofauna is numerically dominated by sciaenids such as Atlantic croaker (*Micropogonias undulatus*), spot (*Leiostomus xanthurus*), silver seatrout (*Cynoscion nothus*), and star drum (*Stellifer lanceolatus*). Sciaenids are more typical of the demersal assemblage inhabiting the northern Gulf of Mexico than the assemblage found 50 km south along Florida's east coast (south of Areas C1 and C2). The contribution of these species to the northern assemblage decreases in a southerly direction, with sciaenids being uncommon to rare in the vicinity of Areas D1 and D2. Common groups found in shelf waters of the southern sand resource areas include searobins (*Prionotus* spp.), cusk-eels (*Lepophidium* spp.), snake eels (*Myrichthys* spp.), conger eels (*Hildebrandia* spp., *Heteroconger* spp.), and lizardfishes (*Synodus* spp., *Trachinocephalus myops*). These taxa are not as abundant as the sciaenids, thus the overall density of fishes in the southern region is likely to be much lower than that found in the mid- and northern sand resource areas.

Spawning is not well known for fishes in the entire region. However, Herrema et al. (1985) listed spawning periods for some common demersal soft bottom species (Table 2-1).

Endangered status of the smalltooth sawfish (*Pristis pectinata*) was finalized on 1 May 2003 (50 CFR Part 224). Critical habitat has not been defined and data are being collected on life history and biology of this species. Information that follows was obtained from NMFS (2000). The smalltooth sawfish is distributed in tropical and subtropical waters worldwide. Within U.S. waters, it was historically distributed throughout the Gulf of Mexico and along the Atlantic coast to North Carolina. This species has become rare in the northern Gulf of Mexico during the past 30 years and its known range is now reduced to the coastal waters of Everglades National Park in extreme southern Florida. Fishing and habitat degradation have extirpated the smalltooth sawfish from much of this former range. The smalltooth sawfish normally inhabits shallow waters (10 m or less) often near river mouths or in estuarine lagoons over sandy or muddy substrates, but also may occur in deeper waters (20 m) of the continental shelf. Shallow water less than 1 m seems to be important nursery

Table 2-1. Months of occurrence of demersal soft bottom[1], demersal hard bottom[2], and pelagic[3] fishes found in spawning condition off Hutchinson Island, Florida from January 1976 to June 1984 (Source: Herrema et al., 1985).

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Lesser electric ray (*Narcine brasiliensis*) [1]						■						
Ladyfish (*Elops saurus*) [3]				■					■	■		
Purplemouth moray (*Gymnothorax vicinus*) [2]										■		
Sooty eel (*Bascanichthys bascanium*) [1]	■											■
Shrimp eel (*Ophichthus gomesi*) [1]		■		■								■
Palespotted eel (*O. ocellatus*) [1]	■											
Yellowfin menhaden (*Brevoortia smithi*) [3]	■	■	■	■							■	■
Atlantic menhaden (*B. tyrannus*) [3]	■	■	■								■	■
Menhaden (*B. smithi x tyrannus*) [3]	■	■	■									■
Scaled sardine (*Harengula jaguana*) [3]				■								
Atlantic thread herring (*Opisthonema oglinum*) [3]		■	■	■	■			■				
Spanish sardine (*Sardinella aurita*) [3]					■			■				
Cuban anchovy (*Anchoa cubana*) [3]		■		■								
Striped anchovy (*A. hepsetus*) [3]		■										
Longnose anchovy (*A. nasuta*) [3]				■								
Inshore lizardfish (*Synodus foetens*) [1]	■											
Hardhead catfish (*Arius felis*) [1]						■	■					■
Gafftopsail catfish (*Bagre marinus*) [1]			■									
Atlantic midshipman (*Porichthys plectrodon*) [1]		■										
Blotched cusk-eel (*Ophidion grayi*) [1]	■	■										
Bank cusk-eel (*O. holbrooki*) [1]	■	■		■	■	■			■		■	
Mooneye cusk-eel (*O. selenops*) [1]				■								
Lined seahorse (*Hippocampus erectus*) [1]		■			■					■		
Bull pipefish (*Syngnathus springeri*) [1]	■											
Tarpon snook (*Centropomus pectinatus*)												■
Snook (*C. undecimalis*)												■
Rock sea bass (*Centropristis philadelphica*) [1]	■	■	■									
Sand perch (*Diplectrum formosum*) [1]			■									
Bluefish (*Pomatomus saltatrix*) [3]	■	■	■	■	■	■	■		■	■		
Blue runner (*Caranx crysos*) [3]					■	■	■	■				
Atlantic bumper (*Chloroscombrus chrysurus*) [3]	■		■	■	■	■	■	■	■	■		
Round scad (*Decapturus punctatus*) [3]						■						
Leatherjacket (*Oligoplites saurus*) [3]					■	■						
Bigeye scad (*Selar crumenopthalmus*) [3]							■				■	■
Atlantic moonfish (*Selene setapinnis*) [3]						■			■	■	■	
Florida pompano (*Trachinotus carolinus*) [3]		■		■								
Gray snapper (*Lutjanus griseus*) [2]			■									■
Lane snapper (*L. synagris*) [2]				■	■	■	■					
Irish pompano (*Diapterus auratus*) [1]				■	■	■	■		■			
Striped mojarra (*D. plumieri*) [1]					■	■	■					
Silver jenny (*Eucinostomus gula*) [1]					■							
Yellowfin mojarra (*Gerres cinereus*) [1]										■		
Black margate (*Anisotremus surinamensis*) [2]	■		■	■								
Porkfish (*A. virginicus*) [2]		■			■					■		
Tomtate (*Haemulon aurolineatum*) [2]						■						
Sailors choice (*H. parrai*) [2]					■							
White grunt (*H. plumieri*) [2]					■	■						
Pigfish (*Orthopristis chrysoptera*) [1]	■	■	■	■	■							■
Sheepshead (*Archosargus probatocephalus*) [2]	■	■	■	■							■	
Sea bream (*A. rhomboidalis*) [2]				■	■				■			
Silver porgy (*Diplodus argenteus*) [2]	■	■	■	■	■							■
Pinfish (*Lagodon rhomboides*) [1]	■	■	■	■							■	■
Silver perch (*Bairdiella chrysoura*) [1]		■	■									
Striped croaker (*B. sanctaeluciae*) [2]	■	■	■	■		■						
Silver seatrout (*Cynoscion nothus*) [1]	■	■	■	■					■	■	■	■
Weakfish (*C. regalis*) [1]	■	■	■	■					■			■
Banded drum (*Larimus fasciatus*) [1]		■	■	■	■	■			■	■	■	■
Spot (*Leiostomus xanthurus*) [1]	■	■	■	■					■	■	■	
Southern kingfish (*Menticirrhus americanus*) [1]	■	■	■	■	■	■	■	■		■	■	
Gulf kingfish (*M. littoralis*) [1]		■	■	■	■		■	■				
Northern kingfish (*M. saxatilis*) [1]	■						■			■		
High-hat (*Equetus acuminatus*) [2]		■	■	■								
Atlantic croaker (*Micropognius undulatus*) [1]	■	■	■						■	■	■	■
Black drum (*Pogonias cromis*) [1]		■	■									
Sand drum (*Umbrina coroides*) [1]	■	■	■	■					■		■	■
Atlantic spadefish (*Chaetodipterus faber*) [2]			■	■	■							
Striped mullet (*Mugil cephalus*) [3]	■	■									■	■
White mullet (*M. curema*) [3]	■		■	■	■	■	■	■	■	■		■
Great barracuda (*Sphyraena barracuda*) [2]								■				
Guaguanche (*S. guachancho*) [2]							■		■			
Dusky jawfish (*Opistognathus whitehursti*) [2]												■
Bigeye stargazer (*Dactyloscopus crossotus*) [1]				■								
Southern stargazer (*Astroscopus y-graecum*) [1]			■									
Hairy blenny (*Labrisomus nuchipinnis*) [2]		■	■									
Checkered blenny (*Starksia ocellata*) [2]		■										
Oyster blenny (*Hypleurochilus aequipinnis*) [2]	■	■				■	■					
Orangespotted blenny (*H. springeri*) [2]	■	■										
Seaweed blenny (*Parablennius marmoreus*) [2]		■							■			
Seminole goby (*Microgobius carri*) [2]			■									
Atlantic cutlassfish (*Trichiurus lepturus*) [1/3]					■	■		■	■	■	■	■
Frigate mackerel (*Auxis thazard*) [3]					■		■					
Little tunny (*Euthynnus alletteratus*) [3]							■					
Spanish mackerel (*Scomberomorus maculatus*) [3]			■	■	■	■	■	■	■			■
Harvestfish (*Peprilus alepidotus*) [3]						■						
Butterfish (*P. triacanthus*) [3]	■	■		■								
Smoothhead scorpionfish (*Scorpaena calcarata*) [2]					■							
Striped searobin (*Prionotus evolans*) [1]	■											■
Blackwing searobin (*P. salmonicolor*) [1]		■	■	■	■			■				
Leopard searobin (*P. scitulus*) [1]	■	■	■	■	■	■			■		■	■
Bighead searobin (*P. tribulus*) [1]	■		■			■						
Spotted whiff (*Citharichthys macrops*) [1]		■	■	■								
Southern flounder (*Paralichthys lethostigma*) [1]	■	■										■
Broad flounder (*P. squamilentus*) [1]			■									
Shoal flounder (*Syacium gunteri*) [1]		■										
Lined sole (*Achirus lineatus*) [1]								■				
Naked sole (*Gymnachirus melas*) [1]	■											
Southern puffer (*Sphoeroides nephelus*) [1]		■										

area for young smalltooth sawfish. Smalltooth sawfish grow slowly and mature at about 10 years of age. Females bear live young and the litters reportedly range from 15 to 20 embryos requiring a year of gestation. Diet consists of macroinvertebrates and fishes such as herrings and mullets. The saw is reportedly used to rake surficial sediments in search of crustaceans and benthic fishes or to slash through schools of herrings and mullets.

2.3.1.2 Hard Bottom

Epibiota

Hard bottom habitats on the continental shelf off eastern Florida consist of rock outcrops colonized by various algae, sponges, hard corals, soft corals, fire corals, tunicates, and other sessile invertebrates that constitute the epibiota. Much of the rock substrate underlying these epibiotal assemblages is composed of relict Pleistocene beach ridges that generally parallel the present-day shoreline (Meisburger and Duane, 1971). These ridges follow general trends along a north-south axis and tend to protrude variably above the sedimentary layer in a discontinuous fashion. Exposed rock will vary in relief from a level pavement to ledges as high as 4 m. In areas where rock substrate is exposed for adequate periods of time, epibiota will assemble through larval settlement from the water column. Such assemblages are thought to take decades to develop into mature communities composed of long-lived organisms (Dayton, 1984). Within the region encompassed by the sand resource areas, hard bottom tracts exist in offshore (shelf) and nearshore (0 to 4 m depths) waters. Offshore hard bottom forms three general trends: shallow shelf, intermediate shelf, and outer shelf (Miller and Richards, 1979; Perkins et al., 1997). A single hard bottom trend occurs in nearshore waters of the project area (South Atlantic Fishery Management Council [SAFMC], 1998b; Lindeman and Snyder, 1999).

Epibiota colonizing offshore and nearshore hard bottom varies in taxonomic composition and diversity in both north-south and cross-shelf directions. Variations in light penetration, water temperature, salinity, sedimentation, and circulation all may influence the structure and dynamics of epibiotal assemblages. Unfortunately, there has been no directed study of epibiotal assemblages or environmental factors controlling the assemblages along eastern Florida north of the Palm Beach area. General trends such as the north-south gradient in species diversity and basic taxonomic composition have been described peripherally for some epibiotic taxa, including corals and algae (Humm, 1969; Briggs, 1974; van den Hoek, 1975; Searles and Schneider, 1980; Jaap, 1984), but specific details of assemblage organization within the region remains unknown.

Nearshore hard bottom outcrops along the shoreline are usually composed of beach rock (Anastasia limestone) and subject to frequent sediment burial and erosion caused by high wave energy. Despite this physically demanding environment, several sessile organisms are well adapted and often cover high portions of the exposed rock. One such organism is the sabellarid polychaete *Phragmatopoma lapidosa*, which forms large gregarious colonies commonly referred to as wormrock (Kirtley and Tanner, 1968). Other epibiota common on nearshore hard bottom of the region are boring sponge (*Cliona celata*), as well as brown (*Padina* and *Dictyota*) and red (*Bryothamnion*) algae (Juett et al., 1976). Hard and soft corals are rare in nearshore habtiats, with only *Siderastrea radians*, *Pseudopterogorgia americana*, *P. acerosa*, and *Muricea muricata* occasionally occurring. Wormrock supports associated assemblages of organisms such as decapod crustaceans (Gore et al., 1978).

Offshore hard bottom trends generally support more dense and diverse epibiotal assemblages than those found on nearshore hard bottom (e.g., Goldberg, 1973). Although data are sparse for areas north of Palm Beach, some general trends are evident, in particular the latitudinal trend in decreasing diversity and colony size of species such as hard corals. Algae, sponges, hard corals, and soft corals are the most conspicuous components of the epibiota colonizing the offshore hard bottom and are described below.

Algae occur on offshore hard bottom as members of four ecological groups: 1) coralline algae that form crusts over exposed rock substrate; 2) fleshy and filamentous algae that attach to the rock substrate; 3) algae that attach to unconsolidated sediments; and 4) excavating or boring algae (Jaap, 1984). The taxonomic composition of algae of the region includes major algal phyla such as blue-green (Cyanobacteria), brown (Phaeophyta), green (Chlorophyta), and red (Rhodophyta) (Littler and Littler, 2000). Species composition of these groups has not been well documented for the region, but it appears that red algae are most speciose when compared with blue-green, brown, and green (Juett et al., 1976; Eiseman, 1979). Some fleshy species, particularly the green algae *Codium* and *Caulerpa*, undergo explosive blooms near Sand Resource Areas D1 and D2 (Continental Shelf Associates, Inc. and Florida Atlantic University [FAU], 1994). *Codium* blooms were followed by large amounts of decomposing algae accumulating on hard bottom areas, causing death and degradation of sponges, soft corals, and other attached organisms (Continental Shelf Associates, Inc. and FAU, 1994). Offshore hard bottom areas of the region generally support more species of algae than nearshore hard bottom areas (Searles and Schneider, 1980).

Sponges commonly found on offshore hard bottom include ball (*Ircinia* spp.), boring (*Cliona* spp.), loggerhead (*Spheciospongia vesparium*), rope (*Amphimedon* sp.), and various encrusting taxa (*Spiralstrella*; *Mycale*). Sponges cover considerable portions of exposed rock and essentially replace hard corals as the largest colonizers of hard bottom north of Sand Resource Areas D1 and D2 (Miller and Richards, 1979). Large sponges contribute habitat complexity and relief in otherwise low relief hard bottom areas.

Hard corals exist on offshore hard bottom as colonial or solitary forms. These species are most abundant and diverse on hard bottom near the southern sand resource areas (C1, C2, D1, and D2). In this portion of the study area, frequently occurring colonial corals include members of the following genera: *Diploria*, *Isophyllia, Mycetophyllia*, *Montastrea*, and *Solenastrea*. Solitary corals found in this area include *Astrangia* and *Phyllangia*. The most widespread hard coral species in the region north of Areas D1 and D2 is ivory tree coral (*Oculina varicosa*). This species reaches peak coverage and growth in deeper waters of about 100 m near the shelf edge where it forms reefs or banks, but small colonies occur on hard bottom areas throughout the region from Jupiter Inlet to just south of Cape Canaveral (Avent et al., 1977; Reed, 1980). Some *Oculina* reefs have been designated by the SAFMC as marine reserves (see Appendix E**,** Figure E-10) due to their documented importance as habitat for fishes and invertebrates (Reed et al., 1982; Koenig et al., 2000).

Soft corals are common on hard bottom throughout the region and the overall species composition is not known. Species known to occur on shelf hard bottom include *Eunicea*, *Gorgonia*, *Plexaurella*, *Lophogorgia*, and *Pseudopterogorgia* (Jaap, 1984; SAFMC, 1998b).

Demersal Fishes

Offshore and nearshore hard bottom areas of the region provide extensive habitat for fishes (Miller and Richards, 1979; Lindeman and Snyder, 1999). Off central east Florida, offshore hard bottom habitats support at least 255 fish species from 49 families (Gilmore et al., 1981). More recent estimates have increased the number to at least 385 species (Gilmore, 1995). The most speciose families ranked by numbers of species are gobies, parrotfishes, grunts, seabasses, snappers, damselfishes, and wrasses. Most species from these families are considered to be tropical or subtropical in origin, and their distributions are greatly influenced by water temperature.

In addition to water temperature, hard bottom fish distribution and abundance are influenced by the same factors (Gulf Stream, temperature range, shelf width, and habitat diversity) discussed previously for soft-bottom demersal fishes. As with demersal fishes and epibiota, a north-south gradient exists for diversity and composition of hard bottom fishes. The distribution and abundance of tropical fishes varies with latitude and distance across the shelf from the western edge of the Gulf Stream. A more diverse tropical assemblage exists in the southern region of the study area (near Areas C1, C2, D1, and D2) and many of these species are gradually lost or displaced offshore in a northward direction along the shelf. North of Sebastian, Florida (near Areas B1 and B2), warm temperate and subtropical fishes are restricted to a depth band ranging from 18 to 55 m with a center of distribution in the 33 to 40 m water depth range. Thermal effects of the Gulf Stream are thought to be the primary cause of this gradient (Miller and Richards, 1979).

Nearshore hard bottom habitats support an estimated 192 fish species (Gilmore et al., 1981; Vare, 1991; Lindeman and Snyder, 1999). These species are derived from families of tropical reef fishes such as angelfishes (Pomacanthidae), butterflyfishes (Chaetodontidae), damselfishes (Pomacentridae), wrasses (Labridae), parrotfishes (Scaridae), surgeonfishes (Acanthuridae), snappers (Lutjanidae), and porgies (Sparidae). One species of tropical origin, striped croaker (*Bairdiella sanctaluciae*), is found in the U.S. only in the region from Jupiter to Sebastian. Abundant species associated with nearshore hard bottom habitats include sailors choice (*Haemulon parra*), porkfish (*Anisotremus virginicus*), cocoa damselfish (*Stegastes variabilis*), silver porgy (*Diplodus argenteus*), and hairy blenny (*Labrisomus nuchipinnis*). Many of these species are present as early life stages, indicating the importance of nearshore hard bottom as essential fish habitat (Lindeman and Snyder, 1999).

Offshore hard bottom areas support a suite of species similar to that found on nearshore hard bottom, but diversity is generally higher. Again, most of these species are reef fishes of tropical origin, and several examples of the transitional nature of the region are found. Mutton snapper (*Lutjanus analis*), yellowtail snapper (*Ocyurus chrysurus*), sailors choice (*Haemulon parra*), schoolmaster (*Lutjanus apodus*), and dog snapper (*Lutjanus jocu*) reach northern limits within the area encompassed by the sand resource areas (Gilmore and Hastings, 1983). There is some cross-shelf segregation of species in the area, but this is more evident in the northern portion of the study area where inshore temperature ranges are more variable and tropical elements of the assemblage are displaced offshore. Nevertheless, the most obvious cross-shelf faunal break occurs at the outer shelf. Species common on deeper reefs but not generally found shallower than 30 m are wrasse bass (*Liopropoma eukrines*), bank butterflyfish (*Chaetodon aya*), tattler (*Serranus phoebe*), and yellowtail reeffish (*Chromis enchrysurus*). Species that typify intermediate reefs are blue angelfish (*Holacanthus bermudensis*), spotfin butterflyfish (*Chaetodon ocellatus*), reef butterflyfish (*C. sedentarius*), jacknife-fish (*Equetus lanceolatus*), and hogfish (*Lachnolaimus maximus*).

Most hard bottom species found in the study area spawn within the region. Some species, such as gag (*Mycteroperca microlepis*), may migrate into the region for spawning. Table 2-1 presents spawning times for some hard bottom species off Hutchinson Island, Florida.

In addition to natural hard bottom, artificial reefs and structures play hard bottom roles. Concrete, fiberglass, limestone, steel, and various other materials have been accidentally or purposely sunk on the shelf within the study area (see Appendix E, Figures E-6, E-8, E-9, and E-10). Most of the same epibiota and fishes discussed above will colonize artificial structures within this area.

2.3.2 Pelagic Environment

2.3.2.1 Fishes

Pelagic fishes are represented by 200 species in the region (Gilmore et al., 1981). Primary families occurring in the region are mackerels and tunas (Scombridae), jacks (Carangidae), driftfishes (Stromateidae), anchovies (Engraulidae), and herrings (Clupeidae).

Pelagic fishes can be subdivided into oceanic and coastal pelagic components. Oceanic pelagic species are the highly migratory epipelagic fishes including billfishes *Istiophorus platypterus*, *Makaira nigricans*, and *Tetrapterus* spp., tunas *Thunnus* spp., *Euthynnus alleteratus*, and *Katsuwonus pelamis*, wahoo (*Acanthocybium solanderi*), and dolphin (*Coryphaena* spp.) that rarely venture far into shelf waters, preferring the warmer and clearer Gulf Stream. These species will enter shelf waters, especially when environmental conditions are optimum, but they are more common within the Gulf Stream. Because the Gulf Stream is very close to shore in this region, particularly in the southern portion of the study area, oceanic pelagic fishes will often occur in the vicinity of the sand resource areas.

Another group of fishes found in oceanic waters are those species that associate with drifting flotsam. Floating seaweed (the brown alga *Sargassum*), jellyfishes, siphonophores, and driftwood attract juvenile and adult epipelagic fishes (Dooley, 1972; SAFMC, 2002). As many as 100 fish species are closely associated with floating *Sargassum* at some point in their life cycle, but only 2 spend their entire lives there: the sargassumfish (*Histrio histrio*) and sargassum pipefish (*Syngnathus pelagicus*) (Dooley, 1972; SAFMC, 2002). Most fishes associated with *Sargassum* are temporary residents, such as juveniles of species that reside in shelf or coastal waters as adults. However, several larger species of recreational or commercial importance, including Atlantic bonito, blackfin tuna, dolphin, little tunny, skipjack tuna, wahoo, and yellowfin tuna, feed on small fishes and invertebrates attracted to *Sargassum*.

Coastal pelagic species prefer shelf waters and usually range from near shore to the shelf break. Coastal pelagic fishes can be divided into two ecological groups. The first group includes large predatory species such as bluefish (*Pomatomus saltatrix*), cobia (*Rachycentron canadum*), jacks (*Caranx* spp.), king (*Scomberomorus cavalla*) and Spanish (*S. maculatus*) mackerels, little tunny (*Euthynnus alletteratus*), and sharks (*Carcharhinus* spp.). With the exception of sharks that tend to be slow growing and have low fecundity, these species typically form schools, undergo migrations, grow rapidly, mature early, and exhibit high fecundity. Each of these species is important to some extent to regional recreational and commercial fisheries. The second group exhibits similar life history characteristics, but the species are smaller in body size and are planktivorous. This group is composed of anchovies (*Anchoa* spp.), bigeye scad (*Selar crumenophthalmus*), menhaden (*Brevoortia* spp.), round scad (*Decapterus punctatus*), Spanish sardine (*Sardinella aurita*), and Atlantic thread herring (*Opistonema oglinum*). These species form large schools in inner shelf and coastal waters, where they are often preyed on by members of the larger predatory coastal pelagic group.

All members of the coastal pelagic group migrate north and south, and east and west over the shelf area encompassed by the sand resource areas. Migratory patterns for most species are not well known. In general, as water and air temperatures decrease in early winter, bluefish, pompano, and Spanish mackerel will migrate southward along the coast. In mid-shelf waters, cobia and king mackerel migrate from either direction. King mackerel exists in at least two populations in the western Atlantic, the Atlantic group and Gulf of Mexico group (Sutter et al., 1991; Gold et al., 1997). The Gulf of Mexico group migrates from near the Mississippi Delta eastward, then southward around the Florida peninsula, wintering off southeastern Florida (Sutter et al., 1991). The Atlantic population migrates between Cape Hatteras and southern Florida. In winter and spring, both populations migrate to southeastern Florida, where they overlap to an unknown extent (Gold et al., 1997). Little tunny migrate into shelf waters during spring and summer months, moving to shelf edge waters to spawn.

Coastal pelagic fishes spawn in shelf or shelf edge waters. Although precise spawning locations are not well documented, eggs and larvae of most species occur throughout the study area. The Gulf Stream transports spawning products into the study area from other regions, and associated eddies retain locally spawned eggs and larvae within the area. Some pelagic species, such as bigeye scad (*Selar crumenopthalmus*), move from offshore waters into nearshore waters to spawn (Continental Shelf Associates, Inc., 1992). Spawning periods for pelagic species are given in Table 2-1.

Some coastal pelagic species are found in the nearshore environment along sandy beaches from the shoreline to the swash zone (Peters and Nelson, 1987). This habitat occurs along the coast for the entire study area. Nearshore fish assemblages show considerable seasonal structuring. The lowest abundance of all species occurs in winter, with peak numbers found during summer and fall. Large predatory species (particularly bluefish, jacks, sharks, and Spanish mackerel) may be attracted to large concentrations of anchovies, herrings, and silversides that congregate in nearshore areas. Mullets, particularly striped mullet (*Mugil cephalus*) and white mullet (*M. curema*), are seasonal members of the coastal pelagic assemblage when adults migrate downstream to the ocean to spawn. During fall months throughout the study area, large schools of striped mullet migrate along the coast, usually from north to south in response to cold fronts and other atmospheric disturbances.

2.3.2.2 Sea Turtles

Five sea turtle species may occur on the eastern Florida inner shelf (shoreline to the 20-m isobath). In order of abundance, they are the loggerhead, green, hawksbill, Kemp's ridley, and leatherback sea turtles (Table 2-2). In general, this region appears to be an important year-round habitat for juvenile through adult loggerhead and green sea turtles on both the inner shelf and mid-shelf (20- to 40-m isobath). Hawksbill, Kemp's ridley, and leatherback sea turtles also are found year-round, although they primarily utilize the mid-shelf and (in the case of leatherbacks) the outer shelf and continental slope (Teas, 1993).

Table 2-2. Sea turtle species potentially occurring offshore east Florida. Species are listed in order of relative abundance.

Common and Scientific Names	Status[a]	Life Stages Present	Seasonal Presence	Nesting Season
Loggerhead sea turtle (*Caretta caretta*)	T	Adults, subadults, juveniles, and hatchlings	Year-round (most abundant during spring and fall migrations)	April-September
Green sea turtle (*Chelonia mydas*)	T/E[b]	Adults, subadults, juveniles, and hatchlings	Year-round	July-August
Hawksbill sea turtle (*Eretmochelys imbricata*)	E	Adults, subadults, juveniles, and hatchlings	Year-round	June-September
Kemp's ridley sea turtle (*Lepidochelys kempi*)	E	Juveniles and subadults	Year-round (most abundant during spring and fall migrations)	(no nesting in area)
Leatherback sea turtle (*Dermochelys coriacea*)	E	Adults, subadults, juveniles, hatchlings	March-October	March-July

[a] Status: E = endangered, T = threatened under the Endangered Species Act of 1973.
[b] Green sea turtles are listed as threatened except for Florida, where breeding populations are listed as endangered. Due to inability to distinguish between the two populations away from the nesting beach, green sea turtles are considered endangered wherever they occur in U.S. waters.

All sea turtles in U.S. territorial waters are protected under the ESA of 1973. Currently, leatherbacks and Kemp's ridleys are listed as endangered species and loggerheads are listed as a threatened species. Green sea turtles also are listed as a threatened species, except for the Florida breeding population, which is listed as an endangered species. Due to inability to distinguish between the latter two populations away from the nesting beach, green sea turtles are considered as an endangered species wherever they occur in U.S. waters (National Marine Fisheries Service [NMFS] and U.S. Fish and Wildlife Service [USFWS], 1991).

South Brevard County, including beach habitats west of Sand Resource Areas A1, A2, B1, and B2, has the greatest density of sea turtle nests in Florida and probably produces more turtle hatchlings per kilometer than any other beach in Florida (Ehrhart and Witherington, 1987). Loggerhead, green, and leatherback turtles account for most nests in the area (Meylan et al., 1995).

Loggerhead Sea Turtle

The loggerhead sea turtle (*Caretta caretta*), named for its characteristic broad and massive skull, is a relatively large sea turtle. This species occurs throughout tropical, subtropical, and temperate waters of the Atlantic, Pacific, and Indian Oceans (Dodd, 1988). In the western Atlantic, it is found in estuarine, coastal, and shelf waters from South America to Newfoundland. Loggerhead adults and subadults are generalist carnivores, feeding primarily on benthic crustaceans (particularly crabs) and mollusks (Dodd, 1988).

Four genetically distinct loggerhead nesting subpopulations have been identified in the western North Atlantic (Marine Turtle Expert Working Group, 2000). These are 1) the Northern Nesting Subpopulation, extending from North Carolina to northeastern Florida, at approximately 29° N; 2) the South Florida Nesting Subpopulation, extending from 29° N on the Florida east coast to Sarasota on its west coast; 3) the Florida Panhandle Nesting Subpopulation; and 4) the Yucatan Nesting Subpopulation. Loggerhead turtles within the study area belong to the South Florida Nesting Subpopulation.

Loggerhead turtles are present year-round in Florida waters, with peak abundance during spring and fall migrations. Off Cape Canaveral, loggerheads utilize both the inner shelf and mid-shelf during all seasons except winter, when they tend to congregate on the mid-shelf (Schroeder and Thompson, 1987). Henwood (1987) found that three distinct groups of loggerheads (adult males, adult females, and subadults) moved into inner shelf waters off Cape Canaveral at different times of the year. Adult males were most abundant in April and May, adult females from May to July, and subadults during the remainder of the year. These data suggest that nesting adult females are short-term residents that migrate into the area on 2- and 3-year intervals and reside elsewhere during non-nesting years. Adult males do not seem to migrate with adult females but may reside in the vicinity of nesting beaches throughout the year. Subadults forage opportunistically along the Atlantic seaboard, although evidence suggests that a resident population of subadults overwinter in the Canaveral area each year (Henwood, 1987).

Ninety percent of loggerhead nesting in the U.S. occurs in south Florida (Shoop et al., 1985). Their nesting season in southeast Florida (meant here as Brevard County through the Florida Keys) is reported to extend from late April through September. March and April are transitional months for loggerheads off Cape Canaveral, Florida. Juveniles, which are thought to overwinter in the area, depart and are replaced by adult males that migrate into the area to mate (Ryder et al., 1994). The southeast Florida region supports the largest loggerhead nesting aggregation in the western hemisphere (Schroeder and Thompson, 1987). Annual numbers of South Florida Nesting Subpopulation nests in southeast Florida during 1989 to 1998 ranged from 46,295 (1989) to 74,988 (1998), with a mean of 61,731 nests annually (Marine Turtle Expert Working Group, 2000). A study of loggerhead nest distributions along Cape Canaveral found that nesting sites were not distributed randomly and peak nesting areas were revisited annually. In most cases, nest densities were correlated to increased beach slope and decreased offshore bathymetric contours (Provancha and Ehrhart, 1987).

Following nesting activities, many adult loggerheads disperse to islands in the Caribbean Sea, waters off southern Florida, and Gulf of Mexico (Meylan and Bjorndal, 1983; Nelson, 1988). Hatchling loggerheads swim offshore and begin a pelagic existence within *Sargassum* rafts, drifting in current gyres and convergence zones for several years (Marine Turtle Expert Working Group, 1996a). At approximately 40 to 60 cm carapace length, juveniles and subadults move into nearshore and estuarine areas, where they become benthic feeders for a decade or more prior to maturing and making reproductive migrations (Carr, 1987).

Green Sea Turtle

The green sea turtle (*Chelonia mydas*), named for the greenish color of its body fat, has a circumglobal distribution in tropical and subtropical waters. The species is made up of several distinct populations. In the U.S., green turtles occur in Caribbean waters around the U.S. Virgin Islands and Puerto Rico and along the mainland coast from Texas to Massachusetts. Adult green turtles are typically found in shallow tropical and subtropical waters, particularly in association with seagrass beds (NMFS and USFWS, 1991).

Juveniles and subadult green turtles are found year-round within the Mosquito Lagoon portion of the Indian River Lagoon system on Florida's east coast. Immature turtles also may be found on the inner shelf along the entire east coast of Florida; however, relatively low numbers of green turtles have been captured in the Cape Canaveral area, presumably the result of this species' habitat preference (Schmid, 1995; Hirth, 1997).

Primary nesting sites in U.S. Atlantic waters are high-energy beaches along the east coast of Florida, primarily during July and August, with additional sites in the U.S. Virgin Islands and Puerto Rico (NMFS and USFWS, 1991; Hirth, 1997). Hatchlings swim out to sea and enter a pelagic stage in *Sargassum* mats associated with convergence zones and eddies.

Adult green turtles commonly feed on algae, seagrasses, and associated organisms, using reefs and rocky outcrops near seagrass beds for resting areas. The major feeding grounds for green turtles in U.S. waters are located in Florida, where the turtles forage mainly on algae and the seagrass *Thalassia testudinum* (Burke et al., 1992). Juveniles transition through an omnivorous stage of 1 to 3 years (NMFS and USFWS, 1991).

Hawksbill Sea Turtle

Hawksbill sea turtles (*Eretmochelys imbricata)* occur in tropical and subtropical seas of the Atlantic, Pacific, and Indian Oceans. In the western Atlantic, hawksbill turtles are generally found in clear tropical waters near coral reefs, including the southeast Florida coast, Florida Keys, Bahamas, Caribbean Sea, and southwestern Gulf of Mexico (NMFS and USFWS, 1993). Along the east Florida coast, hawksbills are probably year-round residents, including adults, subadults, and juveniles (B. Brost, 2002, personal communication, Florida Marine Research Institute [FMRI], St. Petersburg, FL).

Nesting areas for hawksbills in the Atlantic are found in south Florida, Puerto Rico, and the U.S. Virgin Islands. Within the continental U.S., nesting beaches are restricted to the southeastern coast of Florida (i.e., Palm Beach, Broward, and Dade Counties), Florida Keys, and southwestern coast of Florida as noted by Meylan (1992) and the NMFS and USFWS (1993). Hawksbill nesting along the east Florida coast occurs between June and September (B. Brost, 2002, pers. comm.).

Adult hawksbills typically are associated with coral reefs and similar hard bottom areas, where they forage on invertebrates, primarily sponges. Hatchlings are pelagic, drifting with *Sargassum* rafts. Juveniles shift to a benthic foraging existence in shallow waters, progressively moving to deep waters as they grow and become capable of deeper dives for sponges (Meylan, 1988; Ernst et al., 1994).

Kemp's Ridley Sea Turtle

The Kemp's ridley (*Lepidochelys kempi*) is the smallest and most endangered of the sea turtles. Its distribution includes the Gulf of Mexico and the southeast U.S. coast, although some individuals have been found as far north along the eastern seaboard as Nova Scotia and Newfoundland (Marine Turtle Expert Working Group, 1996b). Adult Kemp's ridleys are found almost exclusively in the Gulf of Mexico, primarily on the inner shelf (Byles, 1988).

Kemp's ridleys found along east Florida are primarily juveniles and subadults that use waters of the inner shelf as developmental habitat, although adult-sized individuals also are occasionally found (Schmid and Ogren, 1992). They move northward along the coast with the Gulf Stream in spring to feed in productive, inner shelf waters between Georgia and New England (NMFS and USFWS, 1992a). These migrants then move southward with the onset of cool temperatures in late fall and winter (Lutcavage and Musick, 1985). The Cape Canaveral, Florida area seems to serve as an important winter foraging ground, based on high capture and recapture rates from October to March (Schmid and Ogren, 1992; Schmid, 1995). Telemetry studies of Kemp's ridley migrations off the U.S. east coast suggest that they do not establish residency in dredged shipping channels during this period, although they have been observed on occasion in and around these channels (Gitschlag, 1996). Recent evidence suggests that immature or subadult individuals that move to the Atlantic inner shelf may return to the Gulf of Mexico as adults to nest on Mexican beaches (Witzell, 1998).

Nesting of Kemp's ridleys occurs almost entirely at Rancho Nuevo beach, Tamaulipas, Mexico, where 95% of the nests are laid along 60 km of beach (NMFS and USFWS, 1992a; Weber, 1995; Marine Turtle Expert Working Group, 2000). In the U.S., nesting occurs infrequently on Padre and Mustang Islands in south Texas and in a few other Gulf of Mexico locations (Marine Turtle Expert Working Group, 2000).

After emerging, Kemp's ridley hatchlings swim offshore to inhabit *Sargassum* mats and drift lines associated with convergences, eddies, and rings. Hatchlings feed at the surface and are dispersed widely by Gulf and Atlantic surface currents. After reaching a size of about 20 to 60 cm carapace length, juveniles enter shallow coastal waters and become benthic carnivores (Marine Turtle Expert Working Group, 2000).

Post-pelagic (juvenile, subadult, and adult) Kemp's ridleys feed primarily on portunid crabs, but also occasionally eat mollusks, shrimps, dead fishes, and vegetation (Mortimer, 1982; Lutcavage and Musick, 1985; Shaver, 1991; NMFS and USFWS, 1992a; Burke et al., 1993; Werner and Landry, 1994).

Leatherback Sea Turtle

The leatherback sea turtle (*Dermochelys coriacea*), named for its unique, flexible carapace, is a circumglobal species that is currently subdivided into two subspecies. The Atlantic subspecies, *D.c. coriacea,* inhabits waters of the western Atlantic from Newfoundland to northern Argentina. The leatherback is the largest living turtle (Eckert, 1995), and with its unique deep-diving abilities (Eckert et al., 1986) and wide-ranging migrations, is considered the most pelagic of the sea turtles (Marquez, 1990).

Adult leatherback turtles reportedly occur in east Florida waters primarily during summer, although leatherback turtles were sighted during recent aerial survey programs conducted off northeast Florida from October through April as well (Schroeder and Thompson, 1987; Knowlton and Weigle, 1989; Continental Shelf Associates, Inc., 2002). During these surveys, leatherbacks were sighted on the mid-shelf and inner shelf but not usually near shore (Continental Shelf Associates, Inc., 2002). However, historic data suggest that leatherbacks also may utilize inner shelf waters during periods of local thermal fronts that concentrate food resources (Thompson and Huang, 1993).

Leatherbacks nest on coarse-grained, high-energy beaches in tropical latitudes (Eckert, 1995). Florida is the only location in the continental U.S. where significant leatherback nesting occurs. Nests in Brevard County are relatively few in number when compared with Florida beaches to the south, especially Martin and Palm Beach Counties (NMFS and USFWS, 1992b; B. Brost, 2002, pers. comm.). Nesting along the east Florida coast occurs between late February through early September (Meylan et al., 1995). Because of the cryptic behavior of hatchling and/or juvenile leatherback turtles, very little is known of their pelagic distribution.

Leatherbacks feed in the water column, primarily on cnidarians (medusae, siphonophores) and tunicates (salps, pyrosomas) (Eckert, 1995). The turtles are sometimes observed in association with jellyfishes, but actual feeding behavior has only occasionally been documented (Grant et al., 1996). Foraging has been observed at the surface, but considering their well developed deep-diving capabilities, it also is likely to occur at depth (Eckert, 1995).

2.3.2.3 Marine Mammals

Approximately 27 marine mammal species may occur off east Florida (Table 2-3). However, only a few species are typically found on the inner shelf, including North Atlantic right whale, humpback whale, Florida manatee, bottlenose dolphin, and Atlantic spotted dolphin. Marine mammals listed as endangered or threatened under the ESA of 1973 are discussed first. A subsequent section covers non-listed species. All marine mammals are protected under the Marine Mammal Protection Act of 1972.

Listed Species

Two species of endangered cetaceans are likely to occur in shelf waters off east Florida during at least some part of the year. They are the North Atlantic right whale, *Eubalaena glacialis*, and humpback whale, *Megaptera novaeangliae*. North Atlantic right whales are seasonal “residents” in inner shelf and mid-shelf waters. Inner shelf waters in the northern part of the study area are designated as a critical habitat for North Atlantic right whales (Appendix E, Figure E-10). Humpback whales are only rarely present as transients during their spring and fall migrations.

One endangered sirenian, the Florida manatee (*Trichechus manatus latirostris*), is a year-round “resident” species within Florida inshore and inner shelf waters. Inner shelf waters of the study area are designated as critical habitat for the Florida manatee.

The study area is within the distributional range of four other endangered cetaceans (blue whale, *Balaenoptera musculus*; fin whale, *B. physalus*; sei whale, *B. borealis*; and sperm whale, *Physeter macrocephalus*), but they are considered unlikely to be present within inner shelf waters of the study area. The sperm whale is a deepwater (i.e., water depths offshore of the continental shelf break) species throughout its range (Roden, 1998), and blue, fin, and sei whales would not be expected to occur on the inner shelf as far south as Florida (Waring et al., 1999).

Table 2-3. Marine mammal species potentially occurring offshore east Florida.

Scientific Name	Common Name	Status[a]	Presence[b]
ORDER CETACEA	**WHALES AND DOLPHINS**		
Suborder Mysticeti	**Baleen Whales**		
Family Balaenidae	**Right and Bowhead whales**		
Eubalaena glacialis	North Atlantic right whale	E, S	X
Family Balaenopteridae	**Rorquals**		
Balaenoptera musculus	Blue whale	E, S	O
Balaenoptera edeni	Bryde's whale	none	O
Balaenoptera physalus	Fin whale	E, S	O
Megaptera novaeangliae	Humpback whale	E, S	X
Balaenoptera acutorostrata	Minke whale	none	O
Balaenoptera borealis	Sei whale	E, S	O
Suborder Odontoceti	**Toothed whales**		
Family Physeteridae	**Sperm whales**		
Kogia simus	Dwarf sperm whale	none	O
Kogia breviceps	Pygmy sperm whale	none	O
Physeter macrocephalus	Sperm whale	E, S	O
Family Ziphiidae	**Beaked Whales**		
Mesoplodon densirostris	Blainville's beaked whale	S	O
Ziphius cavirostris	Cuvier's beaked whale	S	O
Mesoplodon europaeus	Gervais' beaked whale	S	O
Mesoplodon mirus	True's beaked whale	S	O
Family Delphinidae	**Dolphins**		
Stenella frontalis	Atlantic spotted dolphin	none	X
Tursiops truncatus	Bottlenose dolphin	none	X
Stenella clymene	Clymene dolphin	none	O
Pseudorca crassidens	False killer whale	none	O
Orcinus orca	Killer whale	none	O
Stenella attenuata	Pantropical spotted dolphin	none	O
Feresa attenuata	Pygmy killer whale	none	O
Globicephala macrorhynchus	Short-finned pilot whale	S	O
Grampus griseus	Risso's dolphin	none	O
Steno bredanensis	Rough-toothed dolphin	none	O
Stenella longirostris	Spinner dolphin	none	O
Stenella coeruleoalba	Striped dolphin	none	O
ORDER SIRENIA	**MANATEES AND DUGONGS**		
Trichechus manatus latirostris	Florida manatee	E	X

[a] **Status**: E = endangered and C = candidate for listing under the Endangered Species Act of 1973 S = strategic stock under the Marine Mammal Protection Act of 1972, as indicated by Waring et al (1999).

[b] **Presence**: (X) presence likely during at least some season; (O) presence possible but unlikely due to geographic range, preference for deeper waters, or uncommon occurrence.

North Atlantic Right Whale

North Atlantic right whales range from Iceland to eastern Florida, primarily in coastal waters. This is the rarest of the world's baleen whales, with a North Atlantic population of between 325 and 350 individuals (New England Aquarium, 2004). Coastal waters of the southeastern U.S. (off Georgia and northeastern Florida) are important wintering and calving grounds for northern right whales, while the waters around Cape Cod and the Great South

Channel are used for feeding, nursery, and mating during summer (Kraus et al., 1988; Schaeff et al., 1993). From June to September, most animals are found feeding north of Cape Cod. Southward migration to calving grounds within inner shelf waters off southeastern Georgia and northeastern Florida occurs from mid-October to early January (Kraus et al., 1993). Designated critical habitat for the northern right whale includes portions of Cape Cod Bay and Stellwagen Bank and the Great South Channel (off Massachusetts) and calving grounds off southeastern Georgia and northeastern Florida. Sand Resource Areas A1, A2, A3, and B1 are located within or in close proximity to the southern extension of the northern right whale critical habitat (Appendix E, Figure E-10). Right whales are commonly found within their designated winter critical habitat during their calving season, which generally extends from approximately December through March.

Humpback Whale

In the northern Atlantic Ocean, humpback whales range from the arctic to the West Indies. During summer, there are at least five geographically distinct feeding aggregations in the northern Atlantic (Blaylock et al., 1995). During fall, humpbacks migrate south to the Caribbean, where calving and breeding occurs from January to March (Blaylock et al., 1995). There have been numerous sightings and strandings off the Mid-Atlantic and southeastern U.S. coast, particularly during winter and spring (Wiley et al., 1995). Humpbacks occasionally stray onto the mid- and inner shelf off northeast and north central Florida, primarily between January and April. These individuals are considered to be strays from the main migratory population, moving southward during this period (S. Swartz, 2002, pers. comm., NMFS, Miami, FL). Humpbacks feed largely on euphausiids and small fishes such as herring, capelin, and sand lance, and their distribution has been largely correlated to prey species and abundance (Blaylock et al., 1995). Calving and breeding occurs in the Caribbean from January to March. Critical habitats along the U.S. eastern seaboard have been identified in the western Gulf of Maine and the Great South Channel (Massachusetts).

Florida Manatee

The West Indian manatee is one of the most endangered marine mammals in coastal waters of the U.S. In the southeastern U.S., manatees are limited primarily to Florida. This group constitutes a separate subspecies known as the Florida manatee (*Trichechus manatus latirostris*) that can be divided into at least two virtually separate populations, one centered along the Atlantic coast and the other on the Gulf coast of Florida (USFWS, 1996). Despite concerted research, it has not been possible to develop a reliable estimate of manatee abundance in Florida. The highest single-day count of manatees from an aerial survey is 1,856 animals in January 1992 (Ackerman, 1995).

Florida manatees inhabit both saltwater and freshwater of sufficient depth (1.5 m to usually less than 6 m) throughout their range. They are usually found in canals, rivers, estuarine habitats, and saltwater bays, but on occasion have been observed as much as 6 km off the Florida coast (USFWS, 1996). During winter months, the manatee population confines itself to inshore and inner shelf waters of the southern half of peninsular Florida and to springs and warm water outfalls (e.g., power plant cooling water outfalls) just beyond northeastern Florida (USFWS, 1996). As water temperatures rise in spring, manatees disperse from winter aggregation areas. During summer, they may migrate as far north as coastal Virginia (USFWS, 1996). Critical habitats for manatees have been identified by the USFWS. Distributions of these critical habitat areas in peninsular Florida are fragmented along the southwest and east coasts and include inner shelf waters within the study area (USFWS, 1996; B. Brooks, 2001, pers. comm., USFWS).

Non-Listed Species

Odontocete Whales and Dolphins

The most common non-listed marine mammal occurring on the east Florida inner shelf is the bottlenose dolphin (*Tursiops truncatus*), which may be present year-round. Bottlenose dolphins in the western Atlantic range from Nova Scotia to Venezuela (Waring et al., 1999). This species is distributed worldwide in temperate and tropical inshore waters. Along the U.S. Atlantic coast, there are two distinct stocks, based on two ecotypes: a coastal, warm water ecotype and a deepwater ecotype (Duffield et al., 1983; Duffield, 1986; Mead and Potter, 1995). The two forms differ in distribution, morphometrics, parasite loads, prey, and DNA markers (Mead and Potter, 1995; Hoelzel et al., 1998). Bottlenose dolphins present within the inner shelf waters of the study area would most likely represent the shallow water ecotype, although this area may include numerous localized, resident stocks (Blaylock and Hoggard, 1994; Waring et al., 1999). Within inner shelf and mid-shelf waters off east Florida, including the study area, bottlenose dolphins feed primarily on fishes, and to a much lesser degree on cephalopods (squids), crustaceans (primarily shrimps), and xiphosurans (horseshoe crabs) (Barros and Odell, 1990; Barros, 1993). Mating and calving occur from February to May. The calving interval is 2 to 3 years. They normally occur in relatively small group sizes, but also may be found in groups of up to several hundred individuals.

Also potentially occurring in inner shelf waters is the Atlantic spotted dolphin (*Stenella frontalis*). Atlantic spotted dolphins range from New Jersey to Venezuela, primarily in warm temperate and tropical waters. This species normally inhabits the outer shelf and slope, although southern populations occasionally come into mid-shelf and inner shelf waters (Waring et al., 1999). Favored prey includes herring, anchovies, and carangid fishes. Mating has been observed in July, with calves born offshore. Atlantic spotted dolphins often occur in groups of up to 50 individuals. Stock structure in the western North Atlantic is unknown.

Other non-listed odontocetes potentially occurring off east Florida but typically in deep waters along the shelf edge and beyond include dwarf and pygmy sperm whales (*Kogia simus* and *K. breviceps*), Clymene dolphin (*Stenella clymene*), false killer whale (*Pseudorca crassidens*), killer whale (*Orcinus orca*), pantropical spotted dolphin (*Stenella attenuata*), pygmy killer whale (*Feresa attenuata*), Risso's dolphin (*Grampus griseus*), rough-toothed dolphin (*Steno bredanensis*), short-finned pilot whale (*Globicephala macrorhynchus*), spinner dolphin (*Stenella longirostris*), and striped dolphin (*Stenella coeruleoalba*) (Roden, 1998; Waring et al., 1999; Wynne and Schwartz, 1999). Although beaked whales (*Mesoplodon* spp. and *Ziphius cavirostris*) also may occur, their distribution at sea is poorly known, and they are believed to be principally deepwater species.

Mysticete Whales

Two non-listed species of mysticete whales may occur in east Florida waters: Bryde's whale (*Balaenoptera edeni*) and minke whale (*B. acutorostrata*). Both are predominantly found in more northerly waters and are infrequently sighted on the east Florida inner shelf (Winn, 1982).